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TREATMENT **APPLICATION**

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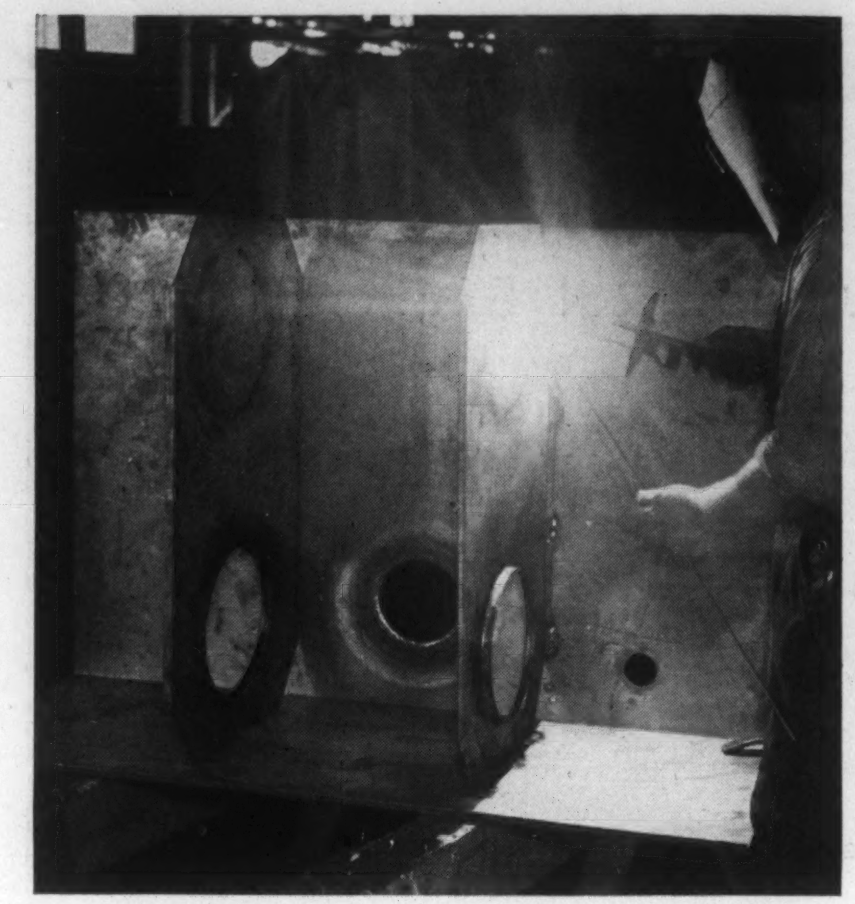

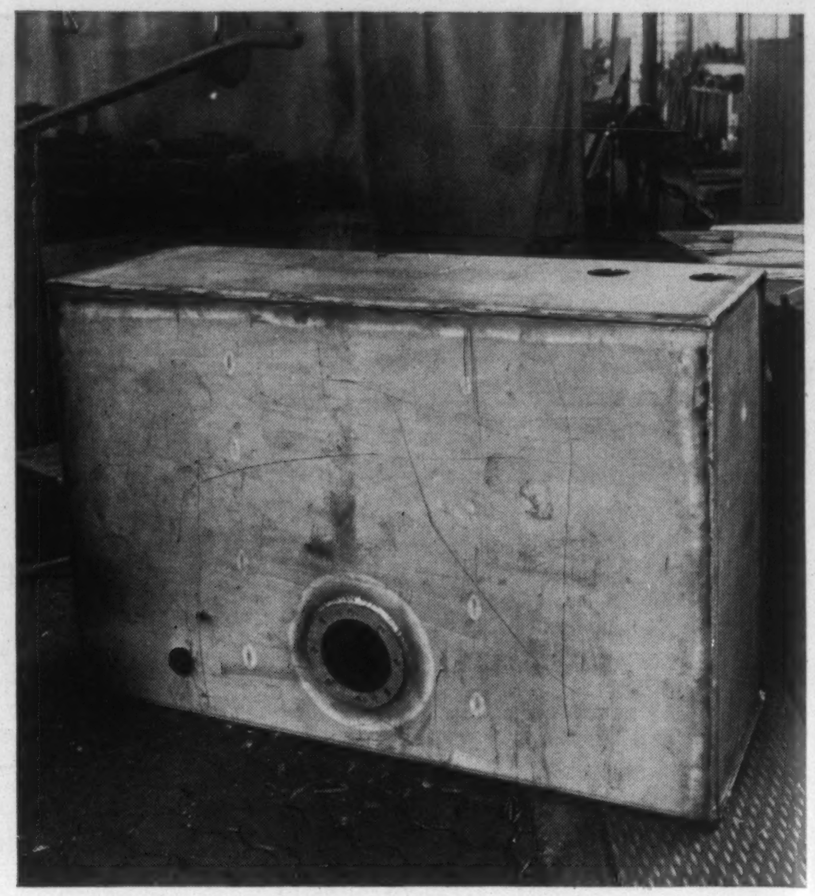

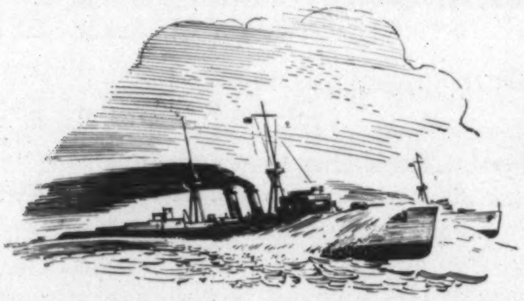

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Herculoy is furnished in hot rolled, cold rolled or cold rolled and annealed sheets, plates, rolls and strips; also hot rolled and cold drawn rods and shafting; tubes and welding rods.

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*U. S. Patent Nos. 1,868,679; 1,924,581; 2,002,460; 2,009,977.

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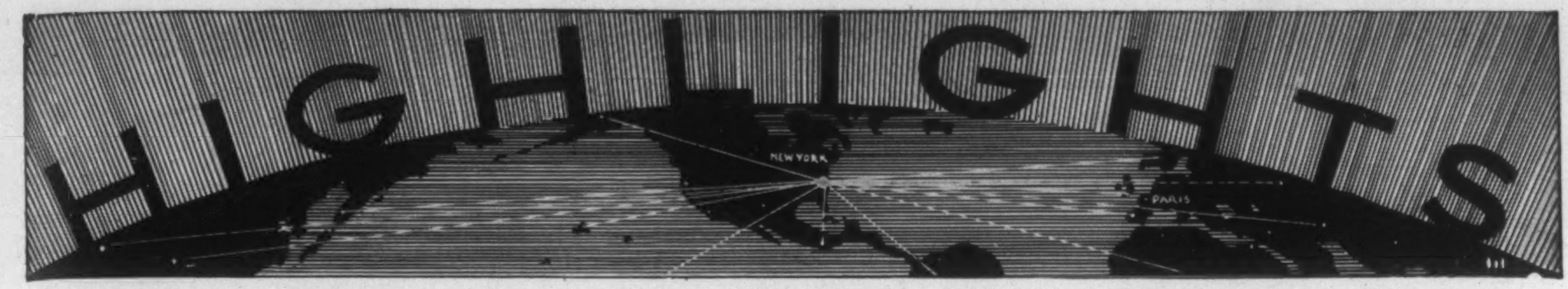


Written by the Abstract Section Editors and the Editorial Staff

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

Defective Car Wheels in Russia!

Government operation of metallurgical outfits as carried out in Russia is interesting. Aksenov and Rosenfeld (page MA 525 R 2) report the casting of 18,000 chilled car wheels in the first 8 months operation of the plant. The inspectors accepted 82. The W. P. A. ought to buy a few foundries and see who can win the booby prize.—H.W.G.

Fewer Bronze Foundry Mixtures

The Institute of British Foundrymen is attempting to eliminate unnecessary foundry mixtures, along lines similar to those being followed in this country at the instigation of Dr. Clamer. 37 customers' specifications for leaded gun-metal, can, the Institute's subcommittee believes, be whittled down to 2 (page MA 526 R 2).—H. W. G.

Silicosis a Problem in Germany

Silicosis is a problem in Germany, as elsewhere. Fritz and Kremer (page MA 554 L 2) state that wet grinding has more hazard of lung injury than dry, despite general views. On the other hand, Jacobs says that the worst trouble is where castings are ground dry and that wet sand blasting eliminates the dust hazard (page MA 537 L 7).—H.W.G.

Zinc in Bearing Bronzes

According to Hansen the idea that much zinc ruins a bearing bronze is hooey (page MA 544 R 2). He speaks up for an alloy with as much as 34 per cent Zn.—H. W. G.

Moly in Alloy Steels

"We are advertised by our loving friends," as the Mellen's baby food ads used to say. Davis (page Ma 545 R 2) comes out strongly for nickel-moly 4640 for gears. No moly endorsement is found in the comments of Lea and Arnold (page MA 545 R 3) who find that 3 per cent Ni 1 per cent Cr, with or without moly, can be embrittled under prolonged heating, with stress. This isn't necessarily the same thing as temper-brittleness, on which there is conflicting evidence, but pretty good proof that moly helps a lot. But Borzdika and Wolfson (page MA 548 L 3) speak up for moly to avoid brittleness on long heating of a 6 per cent Cr steel.—H. W. G.

The Eternal Fitness of Things

A man named Salt reports on corrosion in brine (page MA 549 L 2).—H. W. G.

Time Wasted in Repeating an Investigation

Gvozdov and Nagornov (page Ma 549 L 3) have repeated the work Pilling and Bedworth did some 13 years ago on oxidation of copper and get the same results. Why repeat so well-known an investigation that has already been so thoroughly substantiated, and if it is repeated, why use up paper and ink in publishing the results?—H. W. G.

In Case You Don't Drink Canned Beer

Evans, Goacher and Hurst describe in detail the type of cast iron necessary for use in glass bottle molds (page MA 552 R 8). Growth of cast iron and production of clean iron are stressed.—C. H. H.

More About Insulated Open-Hearths

Soler (page MA 535 L 1) in discussing the application of insulation to open-hearth furnaces, states that design, type of fuel and introduction of the insulation idea to the operating personnel are important factors in assuring success. This is true of other innovations in metallurgical practice. The author also says that factors affecting choice of insulation (and there are many of these), the manner and place of application, must be closely studied.—E.F.C.

High-Frequency Furnaces in Germany

High-frequency furnaces with a capacity of 6 to 8 tons are discussed as to experience and construction by Boer (page Ma 533 L 5). Energy consumption for a 6-ton unit is given as 500 to 600 kw. hr. per ton of steel, with a melting time of about 2 hrs. for a high-grade steel scrap charge.—E. F. C.

Bakelite in a New Role

Shneiderman, a Russian author, states (page MA 526 L 3) that the sweating of porous bronze castings can be prevented by impregnating them with a bakelite varnish under pressure of 3.5 atmospheres and so on. Castings so treated withstood hydraulic pressures of 15 atmospheres and a live steam pressure of 20.—E. F. C.

Rust Removal by Sparks

In discussing modern methods for removing rust from metal parts (page MA 537 L 5) Kappler, a German author, mentions a sparking process—by throwing steel grit rapidly onto the surface to be cleaned so that sparks are produced. Other mechanical and chemical means are reviewed.—E. F. C.

Electric Brazing

Many of the principles and advantages of brazing in continuous electric furnaces with controlled atmospheres are presented by Robiette (page MA 535 R 5). At present its widest application is to steel parts using brass or copper as the brazing alloy. The interesting statement is made that brazing has possibilities for non-ferrous metals such as brass and nickel alloys, silver solders being used for brazing.—E. F. C.

Coloring the Surface of Stainless Steels

A further contribution to the subject of the surface coloring of metals is found in a discussion (page MA 539 L 8) which describes a process developed by Bach for stainless steels. It is claimed that the treatment increases the resistance of stainless steels to corrosion by such acids as HF, HNO_3 and others. It is even suggested that there is a possibility that similar color finishes may be developed on mild steels by the addition of small amounts of alloying elements and modification of the process. More information as to the real merits of the process is declared needed.—E. F. C.

The Spectrograph in Industry

Interest is general in the spectrograph and its scientific and practical applications. Lohse (page MA 541 L 10) describes applications and apparatus for industrial routine purposes and tables of flame spectra and analyses of minerals and solutions are added.—E. F. C. strength—another example of the value of small amounts of the rarer metals

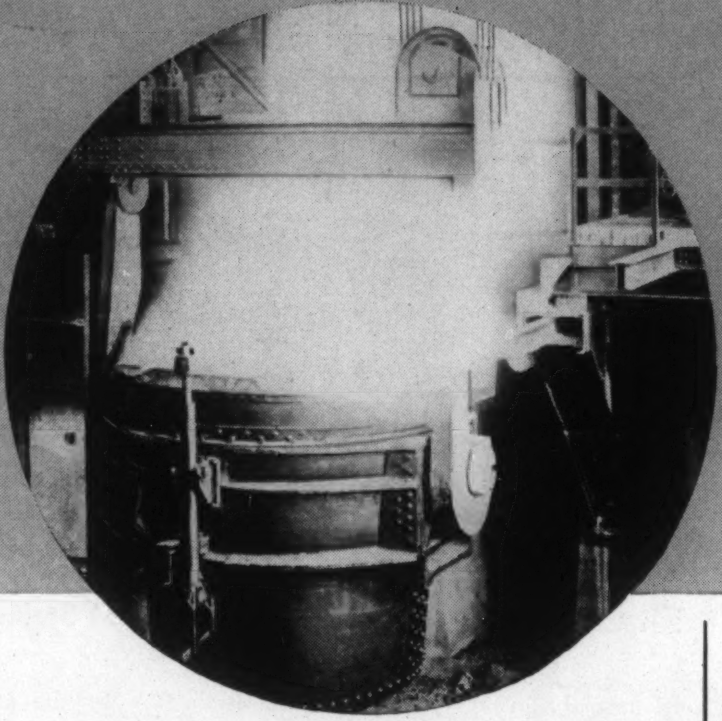
Improving the Properties of Lead with Tellurium

Adding only 0.10 per cent tellurium to pure lead (page MA 545 L 4) effects a marked change in the structure of lead, insuring a finer and more uniform grain size. Such a material is described as more resistant to corrosion than pure lead and to have a higher tensile as alloying materials. This Pb-Te alloy is already being used for tank linings and pipe in the chemical industry.—E.F.C.

Cast Camshafts and Crankshafts

The present trend in using cast instead of forged shafts is discussed in a German article (page MA 552 R 9). The reasons and the advantages of using them are given as well as the experience in their use by automobile and pump manufacturers.—E. F. C.

Silico-Manganese —A Better Deoxidizer



For deoxidizing and scavenging steel quickly and thoroughly, silico-manganese is ideal . . . Silico-manganese dissolves rapidly in the molten bath and unites with oxygen and impurities to form a light, fluid, low-melting, manganese silicate slag that quickly rises to the surface. Thus impurities are removed from the steel, leaving it clean and ready for tapping in 10 to 15 minutes. This quick deoxidation and tapping make possible close control of final analysis . . . Cleaner, more uniform steel results.

Electromet can supply you with four grades of silico-manganese in crushed or lump form ranging from 65 to 70 per cent manganese, 12 to 25 per cent silicon, and up to 3 per cent carbon. Electromet Metallurgists, with years of practical experience in steel making, can help you determine which grade and analysis is best for your purpose, and how to use it to improve your steel. Write for further information or ask to have one of our metallurgists call.

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Miscellaneous Chromium Alloys

• • •

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Ferrosilicon 75%
Ferrosilicon 80 to 90%
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Refined Silicon (minimum 97% silicon)
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Spiegeleisen
Manganese Metal
Manganese-Copper
Miscellaneous Manganese Alloys

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TUNGSTEN

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Calcium-Silicon
Calcium-Aluminum-Silicon
Calcium-Manganese-Silicon

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ZIRCONIUM

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35 to 40% Zirconium
Aluminum-Zirconium

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VANADIUM

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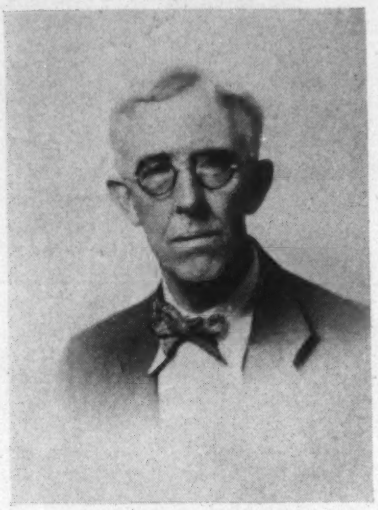
Our Section Editors

(Series Started in July—Concluded in This Issue)

H. F. MOORE is research professor of engineering materials at the engineering experiment station of the University of Illinois, Urbana, Ill. Born at Penacook, N. H., the son of a Yankee mechanic, he entered the University of New Hampshire from which he was graduated in 1898 with the degree of B.S. In 1922 this university bestowed on him the honorary degree of D.Sc. In 1899 he obtained from Cornell University the degree of M.E., with M.M.E. awarded in 1903.



H. F. Moore

As a teacher, Professor Moore was an instructor in machine design at Cornell University from 1901 to 1903. In 1904 he conducted evening classes at Drexel Institute and was in charge of the materials laboratory at the University of Wisconsin, 1905 to 1907. He assumed his present position in 1907.

Professor Moore's practical experience includes his work as a mechanical engineer for the Riehle Bros. Testing Machine Co., Philadelphia, 1903 to 1904, where he designed a number of testing machines, including a 600,000-lb. machine for the University of Illinois. His consulting work includes the U. S. Bureau of Standards, the General Electric Co., Babcock & Wilcox Co., and others.

Two textbooks have been contributed by Professor Moore—"Materials of Engineering"—of which the fifth edition is now in press, and "The Fatigue of Metals" (with J. B. Kommers), both published by the McGraw-Hill Book Co. Other contributions include some 20 bulletins of the Illinois Engineering Experiment Station and many technical articles.

He is a member of the A.S.M.E., A.S.T.M. (past president), A.S.M., A.A.A.S. (past vice-president and chairman of the engineering section) and the British Institute of Metals. His main line of work is strength of materials and his specialties are fatigue of metals, design of testing machines and strain-measuring apparatus.

HENRY S. RAWDON has been a member of the metallurgical staff of the National Bureau of Standards, Washington, for nearly 24 yrs.—being one of the first men appointed to the division of metallurgy on its formation in 1912. He has played an important rôle in its development. Since 1929 he has been chief of the division.

H. S. Rawdon

His early work, after graduation from Michigan State Normal College, was along educational lines in high school science teaching and as school superintendent. Later at the University of Michigan, he was attracted by the then new field of chemical engineering and, as private assistant to the late Dr. E. D. Campbell, became interested in the metallurgy of iron and steel. He entered the Bureau upon graduation in 1912.

During the War, when the entire Bureau was engaged in war activities, Mr. Rawdon had intimate contact with many of the metallurgical problems arising in the manufacture of munitions and artillery. Shortly after the armistice, he was sent abroad to investigate a number of problems in ferrous metallurgy.

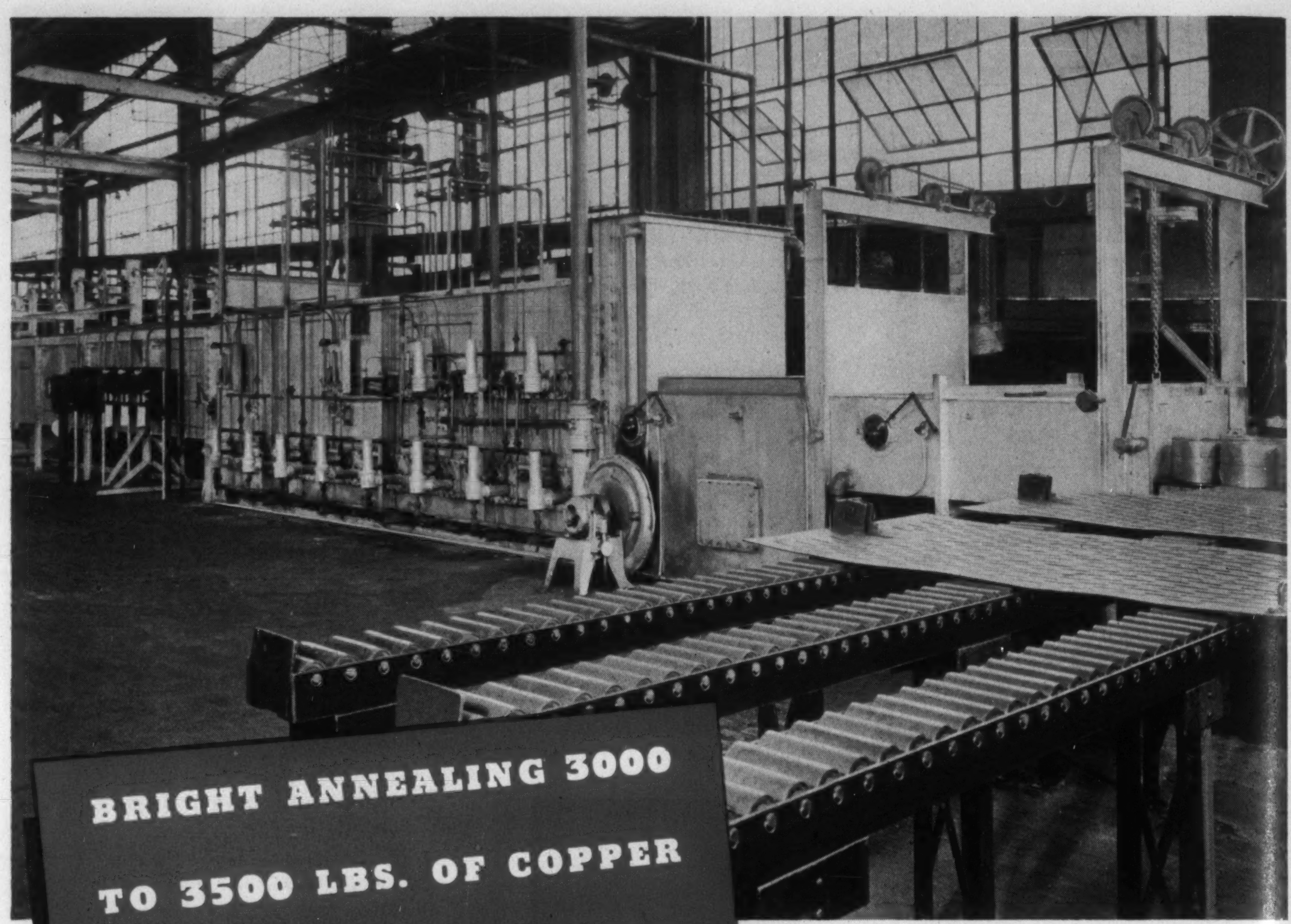
He has written extensively on metallographic subjects and corrosion. His book on "Protective Metallic Coatings," an American Chemical Society monograph, was a pioneer in this field at the time of its appearance.

His duties at the National Bureau of Standards entail extensive co-operation with other federal agencies on metallurgical subjects. He has had wide contact with commercial metallurgical practice and is a member of the following professional metallurgical societies: A.I.M. and M.E., A.S.M. and A.S.T.M. Activity in the latter membership involves numerous committees and in addition he is chairman of the joint research committee on effects of phosphorus and sulphur in steel.

L. S. REID has installed a complete testing laboratory for the Metropolitan Life Insurance Co., New York. He is a graduate of Yale University with the degree of Ph.B. in chemistry and chemical engineering.

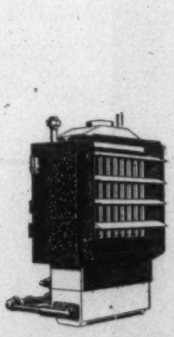
Mr. Reid's experience includes a position with the Doehler Die Casting Co., as a chemical engineer; with the American Cirrus Engine Co., manufacturer of airplane engines, as chief metallurgist; with the Magnetic Analysis Corp., as chief engineer; and with Lucius Pitkin, New York consulting engineers, as associate metallurgical engineer. Mr. Reid is a member of the A.S.T.M., A.I.M. and M.E. and the A.S.M.

L. S. Reid



BRIGHT ANNEALING 3000 TO 3500 LBS. OF COPPER STRIP PER HOUR AT 800° F. IN CONTROLLED ATMOSPHERE

SC Gas-Fired Controlled Atmosphere Bright Annealing Furnace, with SC Radiant Heating Elements, an outstanding SC Development.



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Typical is the installation pictured, which bright anneals 3000 to 3500 lbs. of coiled copper strip per hour, at 800° F., in controlled atmosphere, with a gas consumption of only .472 cu. ft. of 530 BTU city gas per pound for heating, and .161 cu. ft. per pound for atmosphere. Heating is accomplished by SC Gas-Fired Radiant Heating Elements, mounted above and below the conveyor along which the copper strip in coils passes in perforated alloy trays. The material is cooled in a cooling chamber to 150° F. before being discharged. A specially prepared gas mixture is maintained in both the heating and cooling chambers by means of an SC DX Gas Preparation Unit, which prevents oxidation and discoloration. Heat seals prevent air infiltration at charge and discharge ends of the furnace.

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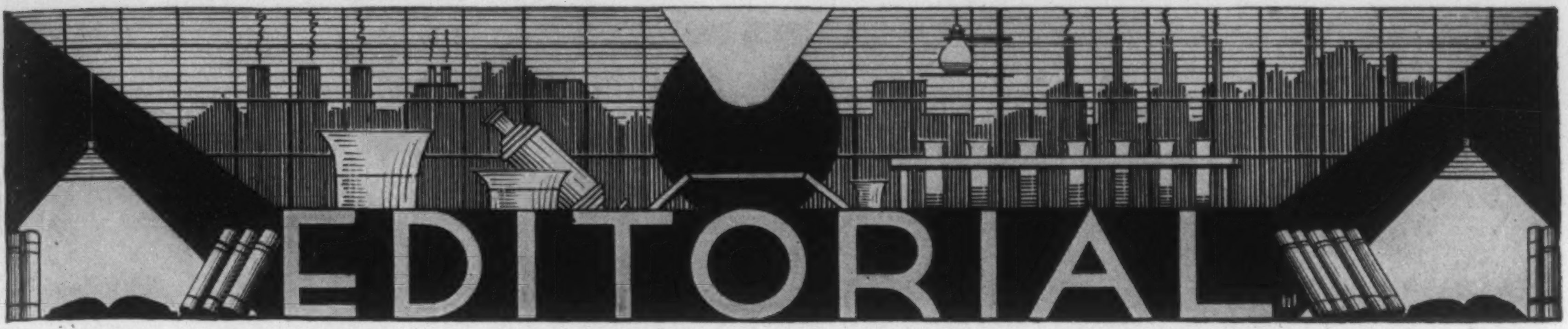

The National Metal Congress

A VISITOR to the National Metal Congress in Cleveland last month came away with many decidedly favorable and encouraging impressions. There were also some of a contrary nature.

Prominent among the former was the size of the attendance, the largest ever recorded, and the expanse and beauty of the exposition. One of the most valuable reactions of such an event is the interest shown in the technical programs. This year this was most marked—comment was prolific that the attendance at the sessions, particularly those of the American Society for Metals and the American Welding Society, was the largest and of the highest quality ever recorded. Even at the first session of the A.S.M. in the morning of the first day the large ballroom of the hotel was filled with 500 to 600 listeners.

At the exposition a striking feature was not only the elaborateness and expansiveness of the booths, particularly those of the leading steel companies, the ferro-alloy and metal producers, but also the quality of the attendance which was reported as unusually satisfactory from the standpoint of the exhibitors. These facts and others, which need not be elaborated on here, reflect a decided upturn in business which is country-wide and which many there considered would inevitably continue, despite any political ramifications or claims.

It was interesting to note from conversations in the lobbies, always a valuable feature, that the metal and alloy industry as a whole has expanded to such an extent that there is actually now a dearth of first class metallurgists. Good men are being eagerly sought. Demands on the technical schools and colleges are insistent. It is certainly to be emphasized that young men who are considering a career should seriously appraise their qualifications for success and aptitude in metallurgy.

On the other side of the picture is the question of the number of papers and sessions. By actual count the five societies, cooperating in the congress, presented on their programs 125 papers and lectures—actually a "hemorrhage of technical information!" All too seldom was it possible to stop the flow long enough for worth-while discussion. These particular meetings were no worse off in that respect than are most technical society meetings. It is a general failing to fill the programs so full that the sessions resemble relay races. A comment frequently heard is "I'm going to stick around the lobby instead of going to the sessions, for I can read the papers later. There won't be time for discussion and that's the only reason for listening to the session."

An unfortunate fact, commented on frequently, was that it was often difficult to hear the paper one was interested in and also that there was too much overlapping of subjects by the societies. In the enthusiasm of organizations which are still young, this is likely to occur, but it is hoped that more coordination of effort in planning programs may ultimately be achieved.

Unquestionably the net result of the week's events indicates that metals and alloys are gaining increasingly intelligent use as engineering materials, largely on account of the basic facts set forth in technical literature.—E. F. C.

Supply and Demand

WE often wonder at the availability of talent in those cases where special skill and specialized training are involved. How does it happen that there are enough authors to produce the steady flow of detective stories, enough undertakers to handle the corpses, enough makers of artificial legs, enough watch repairers and so on?

We suppose that the law of chance rather than the law of supply and demand holds in these cases, i e., out of every 10,000 people a sufficient number will have a peculiar quirk of mind that makes them want to do a particular thing, to supply the need as the population increases. That is, a constant proportion probably comes along to meet a constant need. This hypothesis would account for the undertakers, since their work must bear quite a definite relation to the population.

But those industries which are developing more rapidly than population cannot be taken care of in this automatic fashion. You can't fill a key position requiring special skill by calling in a W.P.A. laborer. This is especially true where technical control and scientific research will be needed at an ever-increasing rate.

In an attractive booklet from Rensselaer Polytechnic Institute, featuring metallurgical, chemical and aeronautic engineering, branches recently housed in a new building there, it is stated that in 1935 only 189 students specializing in metallurgy or metallurgical engineering were graduated from institutions of collegiate rank in the United States and Canada, and that in all classes from freshmen to seniors only 1027 were registered in such courses.

Of course a good many institutions produce pretty good metallurgical raw material in the form of chemists, physicists and engineers, who have a fair introduction to metallurgy, without calling them metallurgists, and sometimes the broader background of such men may make them more useful than if they had specialized as metallurgists. But if we double or triple the R.P.I. figures, even then the crop would hardly seem enough to go around, when we consider that a considerable proportion of the men who start out as metallurgists will ultimately wind up as technical salesmen rather than as operating or research men.—H.W.G.

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Manufacture of Ford Camshafts

How Metallurgical Control is Achieved

By EDWIN F. CONE

THE METALLURGY OF automobile camshafts varies according to the ideas of the different producers of automobiles. Some are made as forgings or as castings—many are now produced as an alloy cast iron. If an alloy iron is used, its composition varies widely and in most cases its heat treatment is essential.

Unique in this particular field is the metallurgy of the Ford camshaft. It is an alloy cast iron but the method of manufacture, and in particular the metallurgical control involved, eliminate the necessity for any heat treatment. The Ford product is essentially different from all others in that it uses such an alloy composition that, though heat treatment is unnecessary, the cam tip is file hard, with the core or points where machining is involved soft enough for good machinability. This tip is really a chilled (white) iron with the core left gray and machinable. The story of this interesting achievement in metallurgy is told in this brief article.

A composition of suitable analysis and a rigid control of this are essentials in accomplishing the Ford objective. Another necessary essential for success is the maintenance of definite pouring temperatures and, besides this, careful attention is directed to the sand mixtures, the choice of pig iron and the method of firing the cupola. A discussion of some of these assentials follows.

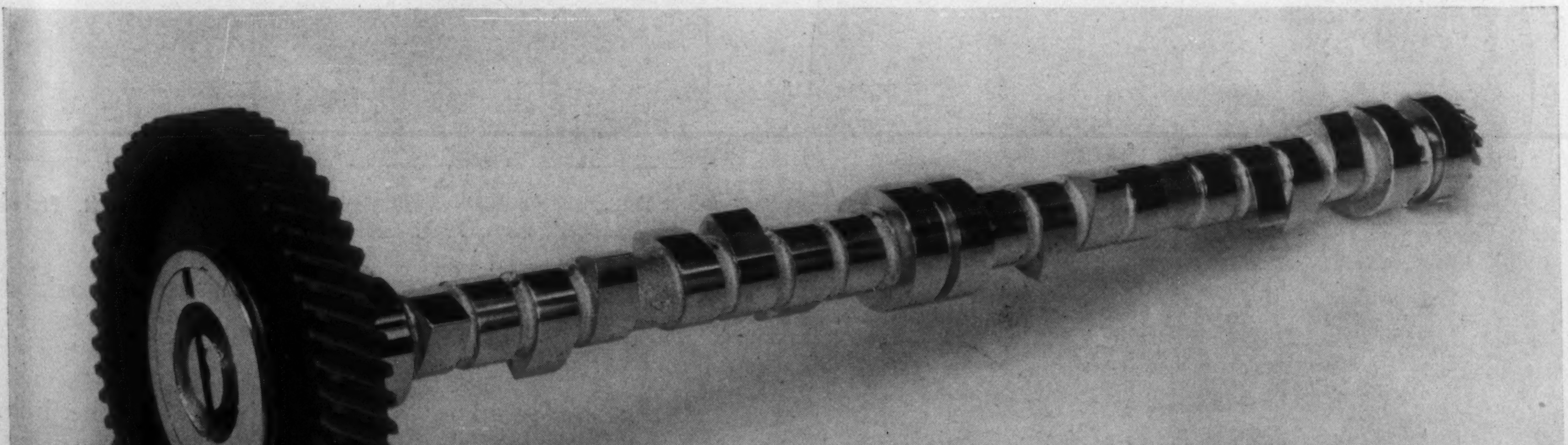
It took some investigation and experimentation to select a suitable analysis but the following one was finally decided upon:

	Per Cent
Carbon	3.30 to 3.65
Manganese	0.15 to 0.35
Silicon	0.45 to 0.55
Chromium	None to 0.25
Copper	2.50 to 3.00
Phosphorus	0.05 max.

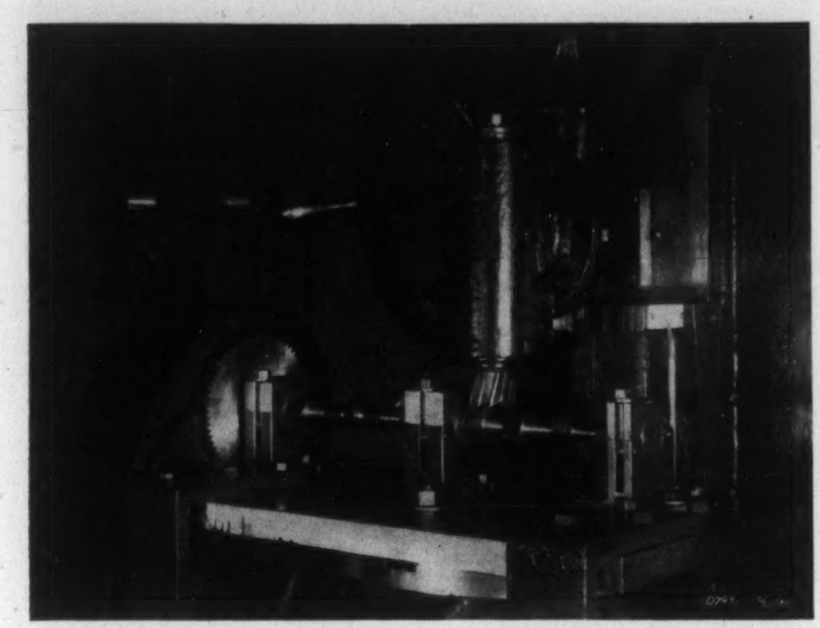
The pig iron used in the charge is about a 1 per cent silicon Bessemer iron with reasonably low phosphorus. This is charged, together with back scrap from gates and risers, into the cupola with a small amount of steel scrap and scrap copper. This charge is made up in correct proportions to give the analysis specified. A rather high coke ratio is maintained in the charge with an air pressure of 16 to 18 oz.

Naturally, with the utmost care in the selection of

One of the Ford Finished Camshafts with the Timing Gear Attached.

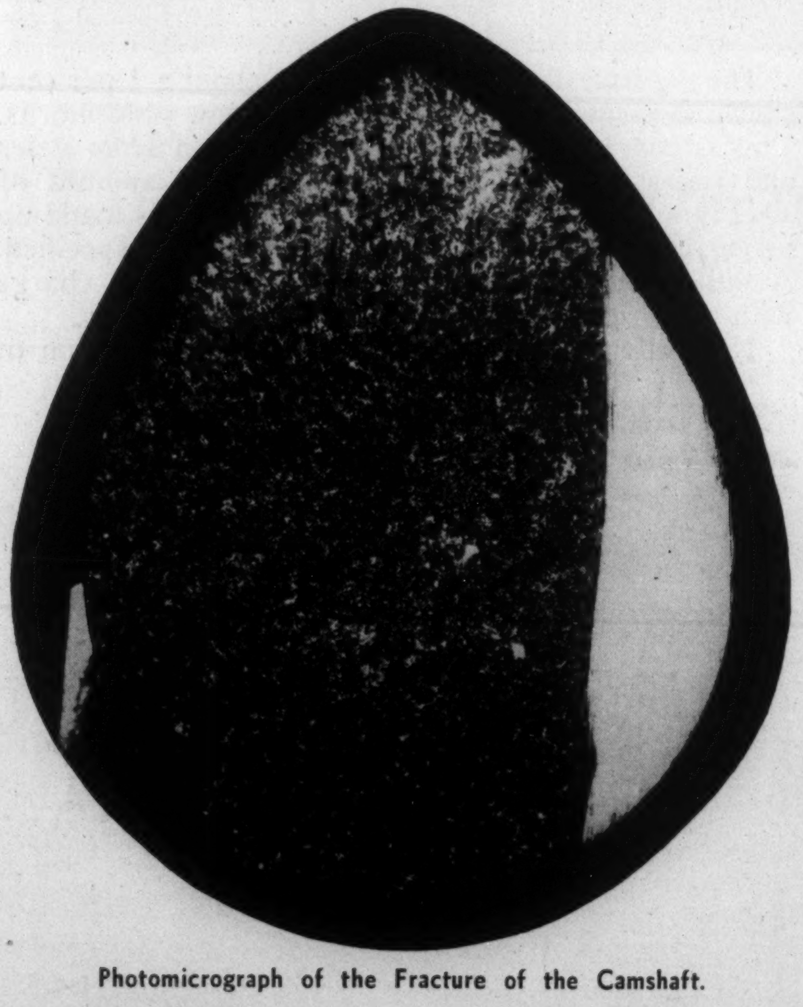


pig iron and in the control in charging, some deviation in the metal from the cupola is inevitable. This being so, it became necessary to establish some kind of rapid test which would enable one to correct very quickly any variations in the composition.



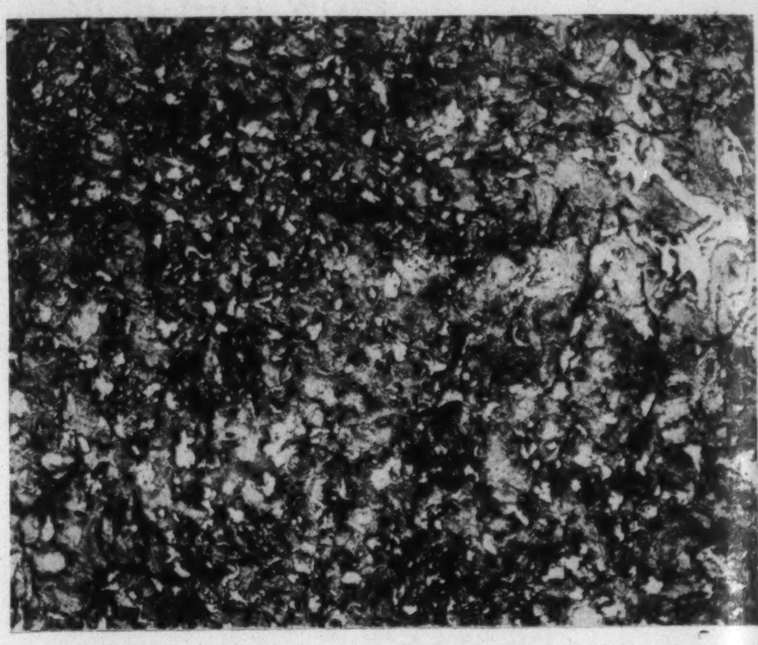
Another Machining Operation to Which the Camshaft is Subjected.

To accomplish this a round bar, cast in a dry sand mold 1½ in. by 6 in., is used. A sample of the metal is poured into one of these from each ladle and the fracture carefully examined for structure by an experienced operator. Also a cam is examined periodically at shake-out and the depth of chill of the cam tip and the fracture are noted. The cam tips are to be file hard with a Brinell of 418, while the main bearing and other parts of the shaft are held at a minimum of 255 Brinell.

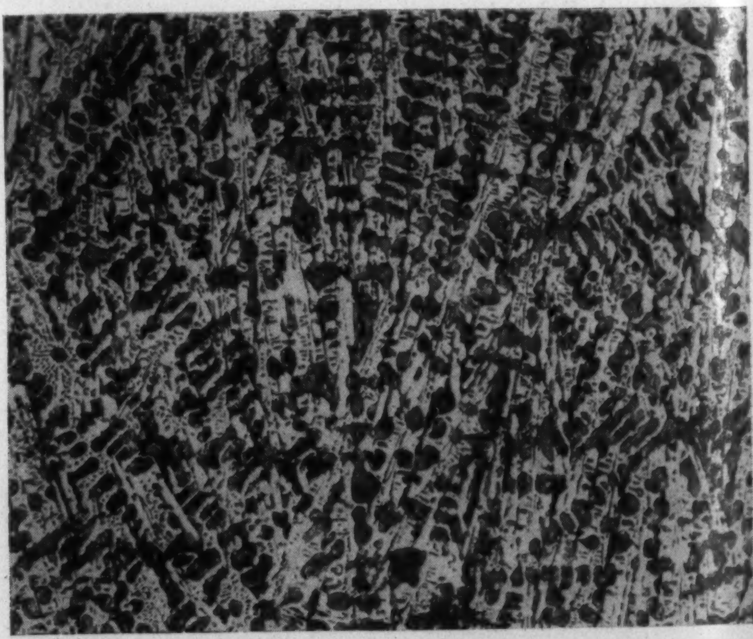


Photomicrograph of the Fracture of the Camshaft.

By means of the two quick tests just described, the metal is never allowed to get out of control to any extent. Periodic chemical analyses are also made. If these tests of fractured bars indicate that the iron is swinging too far to the gray state with a consequent softening of the tips, up to 0.25 per cent chromium is added to the ladle. This is claimed to eliminate the loss of several ladles of metal before corrections can be made in the cupola. If, on the other hand, the metal swings too far to the white condition with a consequent hardening of the core and the points that must be machined, ferrosilicon may be added to the ladle. This renders the metal softer. Careful observance of these metallurgical expedients results in a rigid control of the composition so that a cam shaft is produced as cast which meets all mechanical requirements.

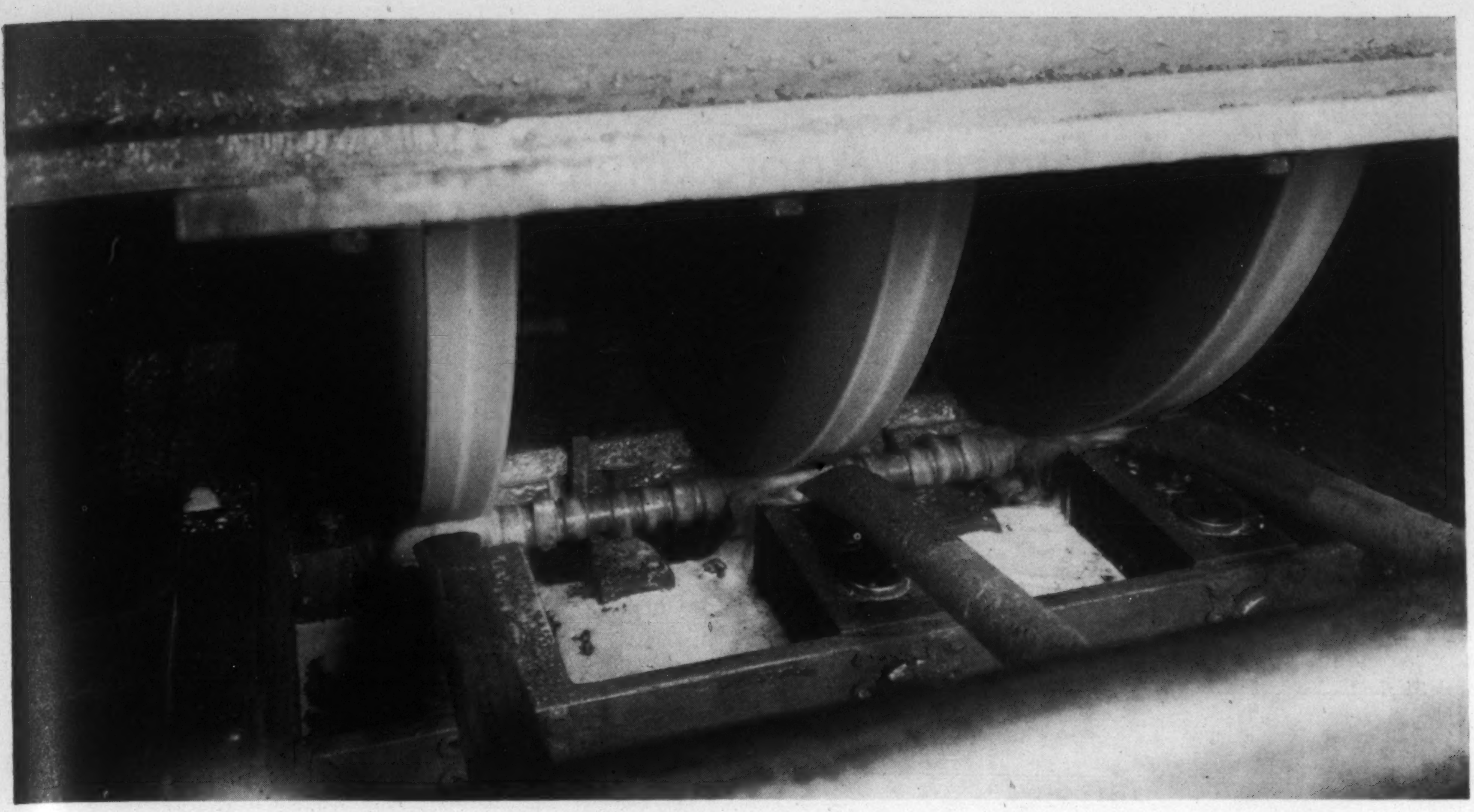


Structure of the Core of the Camshaft. Etched with 5 per cent nital. Magnification, 100 diameters.



Structure of the Chilled Section, or Point, of Camshaft. Etched with 5 per cent nital. Magnification, 100 diameters.

Some of the reasons for selecting the composition here described are reported to be as follows: It was necessary to have an analysis that could be cast with a minimum amount of foundry loss and defects and one that bordered on a mottled iron. A white iron composition was chosen, the high carbon insuring fluidity and the necessary carbides. The silicon was kept low so as not to prevent the formation of these carbides. It is pointed out that of course this selected analysis will make a cam with a chilled tip and a soft core but great difficulty in the experimentation was experienced in controlling the depth of chill. With a minimum amount of changes in conditions, the metal

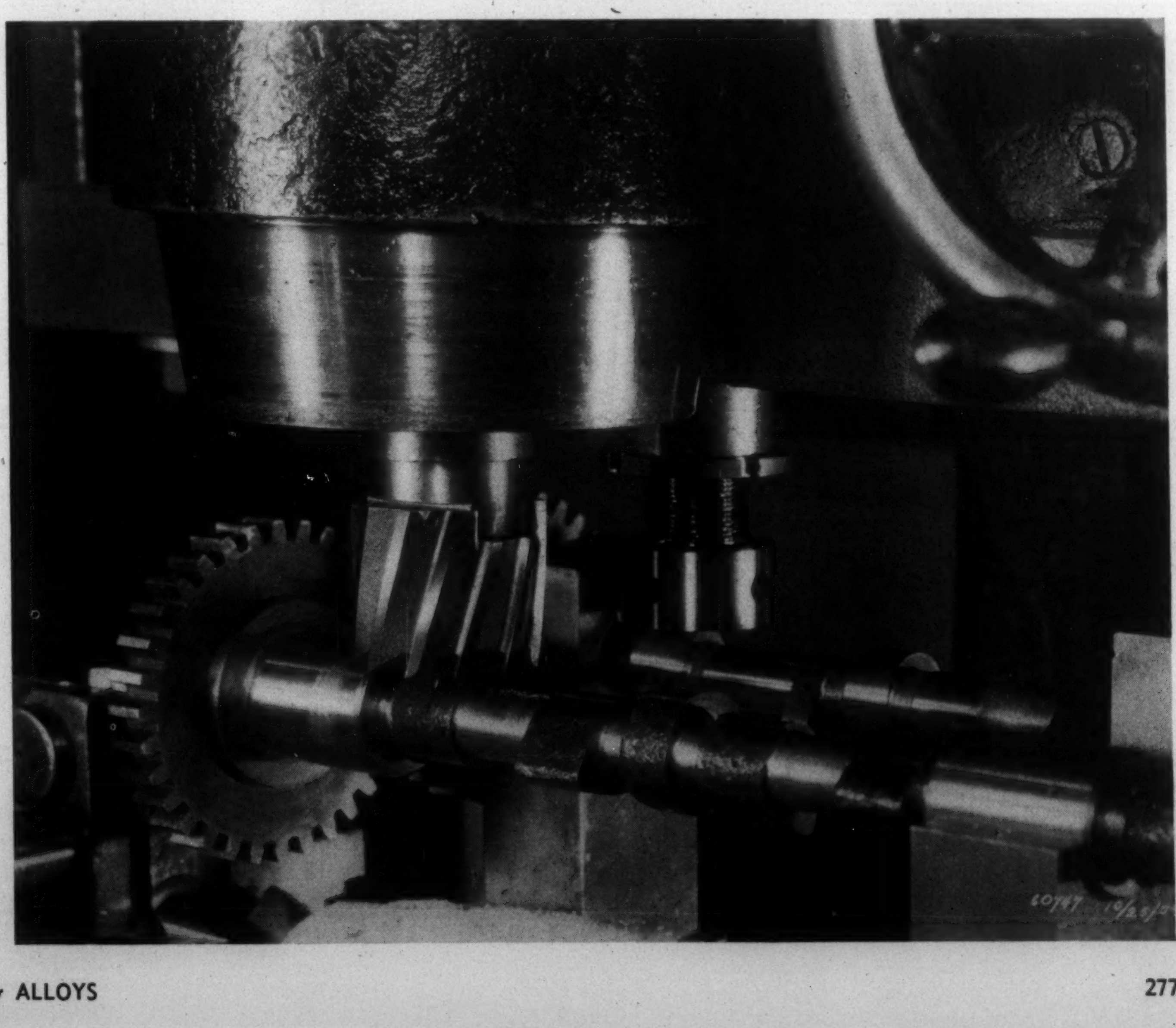


One of the Grinding Operations on a Camshaft.

would go completely white or completely gray.

It was necessary to add some element that would minimize this tendency to go to extremes. Copper has been found by Ford metallurgists to be a very good stabilizer, acting as a graphitizer to prevent the formation of excess carbides in the core. At the same time it allows a thin section like a cam tip to chill. With the presence of copper, there is less tendency of the metal to change to extremes with unavoidable changes in conditions. The use of the small percentage of chromium has been explained.

The shafts are then cleaned in the foundry cleaning room, the main bearings ground on a centerless grinder, the cam ground on an ordinary cam grinder, no machine turning being necessary since the shafts are cast very close to size.



One of the Machining Operations on a Ford Camshaft.

A Simple Approximate Method for Determining Nodule Number

By H. A. SCHWARTZ

Manager of Research, National Malleable & Steel Castings Co., Cleveland.

THE AUTHOR HAS in the past published a method ("The Metallographic Determination of the Size Distribution of Temper Carbon Nodules," METALS & ALLOYS, Vol. 5, June, 1934, page 139), based on earlier work of Scheil, for computing the number of nodules of temper carbon per unit volume from the number and size of their intercepts per unit area. The method is somewhat tedious and might be much simplified if there were some systematic relation between the relative numbers of spheres of the several sizes underlying the original computations.

The chart shows graphically the relation of ΣN, the number of nodules per cubic millimeter to Σn, the number per square millimeter for 31 specimens selected to secure the greatest variety of composition and manufacturing methods. Some of the points are based on a classification into five sizes and some into ten. The two methods appear concordant. In all the specimens, graphitization had reached a point where the nodules were well developed, for example, where graphitization was at least 60 per cent complete. Some specimens recorded were germinated at 700 deg. C. and some at 900 deg. C.

The curved line in the main portion of the illustration represents the most satisfactory smooth curve passing through the array of points. No attempt is made to derive, either by reasoning or by curve fitting, an equation representing this line.

As is particularly evident on consulting the enlarged detail, the lower portion of the curve, up to $n = 30$ or so, is well represented by the equation

$$N = n^2 \qquad (1)$$

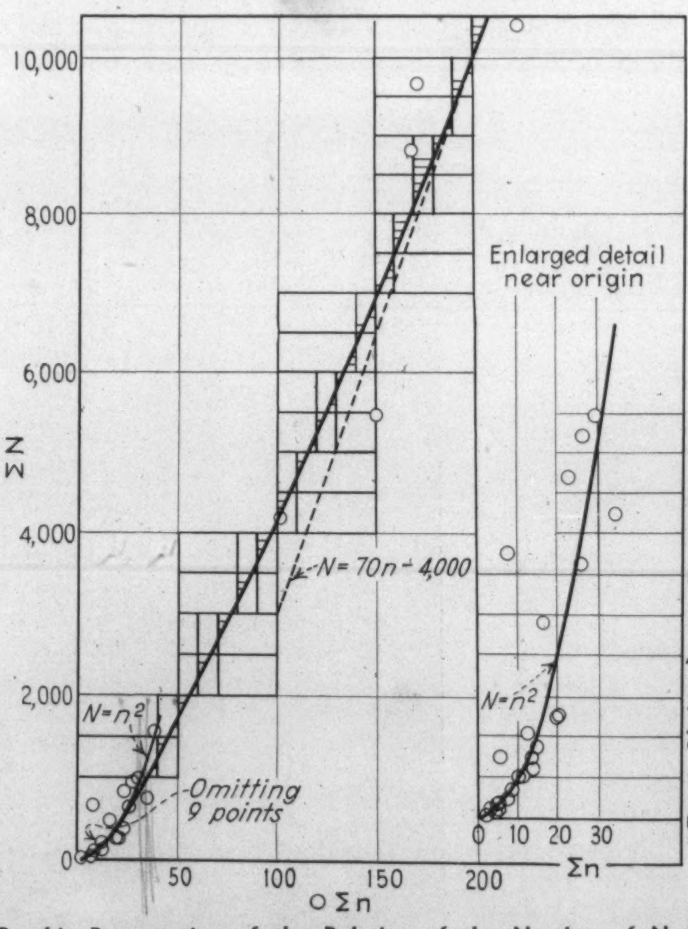
Although the results scatter considerably, the portion of the curve above about $N = 100$ could be represented by the line

$$N = 70n - 4000 \qquad (2)$$

which is shown as a dotted line in the chart. Perhaps the heavy line is merely a transitional line asymptotically approaching equations (1) and (2) in its two limits.

The graphs of the illustration may be used to derive a first approximation of the number of nodules per unit volume from the number per unit area. They *cannot* be used where an accurate comparison of nodules per unit volume is required. For such purposes the calculations must be made completely as described in the reference.

For low values of n, fortunately, including most of the practical cases, the extremely simple quadrati (1) seems to yield rather accurate results. Algebraically combining (1) or (2) with the value of ΣN [N in (1) or (2)] from even the simpler Table 2 of the article referred to and remembering tha $n = \Sigma n$, shows that the present observations are not sufficient to define any particular size distribution. The curves are justifiable only experimentally.



Graphic Presentation of the Relation of the Number of Nodules in Certain Areas for 31 Specimens.

ZINC BRONZE—
COMPOSITION "G"

Treating It for Pressure Tightness

By FRANCIS G. JENKINS

Assistant to Materials Engineer, Fore River Plant, Bethlehem Shipbuilding Corp., Quincy, Mass.

GUN METAL BRONZE is still the most important of all composition metals. This is due to a combination of properties such as strength, toughness, good casting characteristics and excellent resistance to sea water corrosion and erosion and to severe acid conditions.

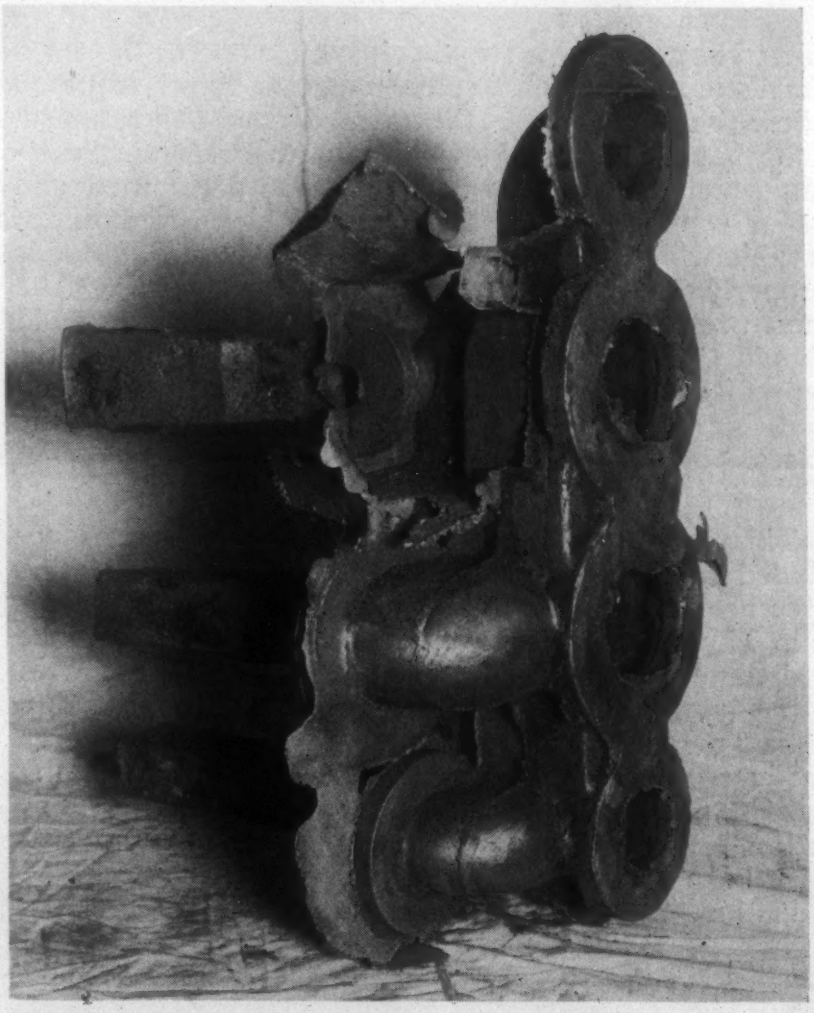
While this bronze has been used for a variety of purposes for many years, it has suffered from the disadvantage that it is sometimes difficult to obtain sound castings—castings that satisfy specified tensile and hydraulic tests. Their liability to internal porosity is particularly serious when subjected in service to hydraulic pressure for which purpose it is otherwise a very suitable material. Unsoundness or porosity in bronze castings may arise from a number of causes, as for example cracks, blowholes, sand inclusions, dross and cold shuts. All of the faults may be avoided by simple foundry technique with the exception, however, of two types, one distinguished as due to gas cavities and the other to the more minute intercrystalline shrinkage channels.

It was the purpose of this paper to review proper practice to avoid gas porosity and to correlate information on the exact cause of and on suitable remedies for shrinkage unsoundness. The work has concentrated on the latter because the methods of avoiding gas contamination are practiced successfully while despite the wealth of material on the subject, interdendritic unsoundness still remains serious.

The zinc bronzes—88 parts copper, 10 parts tin and 2 parts zinc and 88 parts copper, 8 parts tin and 4 parts zinc—are commonly known as admiralty gun metal and admiralty bronze in England; government bronze, gun metal and composition "G" in this country. A modification of the old well known 88-10-2 is the increasingly popular alloy 88-8-4 possessing improved physical properties with increased machinability.

Three Classes of Gas Porosity

SMALL round pin holes on the surface collectively or a large cavity or blowhole with small ones around it in cope or drag after skin of casting is removed are due to gas. Investigators have divided so called gas porosity into three classes:

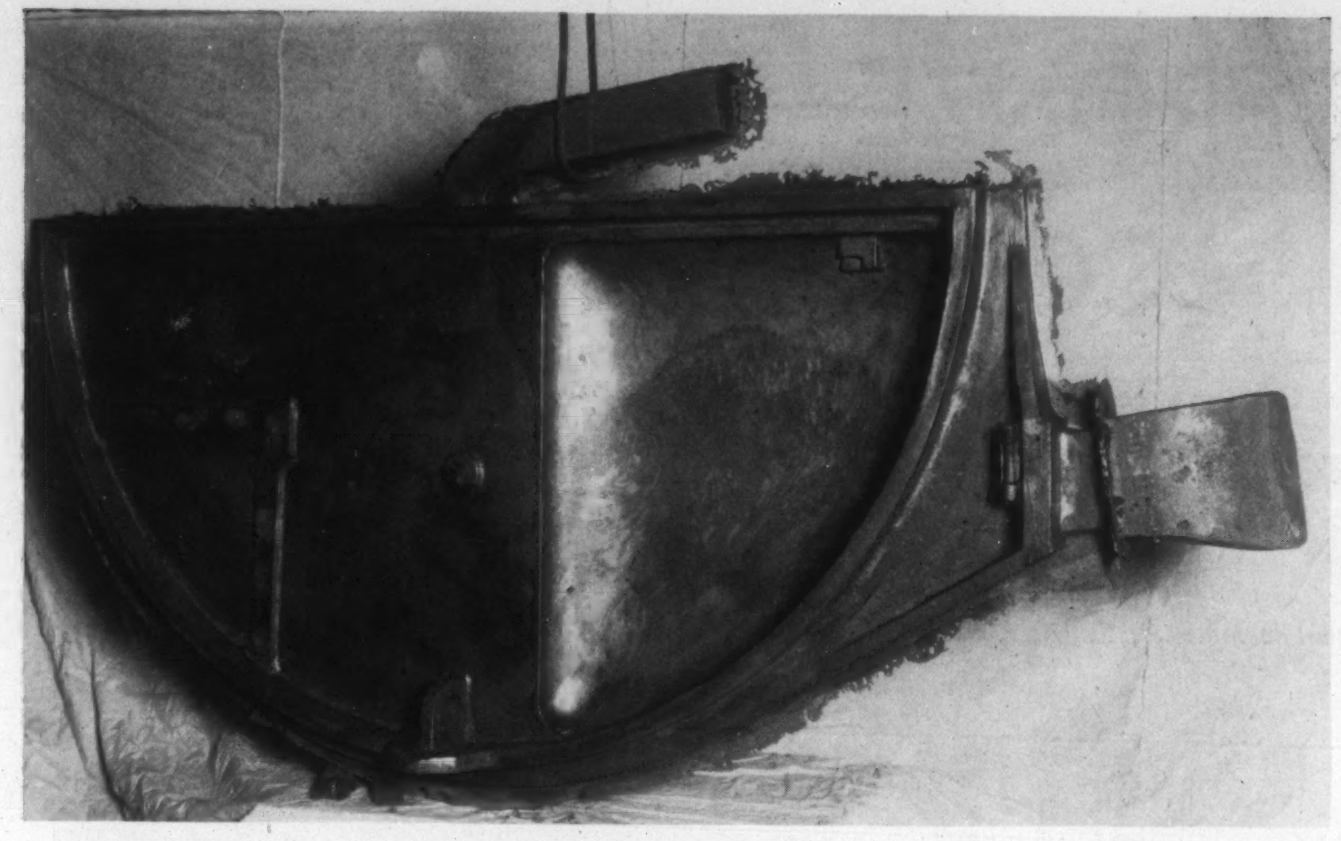


Manifold Body for a Pump Discharge Showing Gates and Risers. (Required hydrostatic test—150 lbs. per sq. in.)

1. Occluded mold gases including steam, a mechanical fault.
2. Occluded metallic oxides.
3. Occluded furnace and melting gases including SO_2, CO_2 and CO.

Mold Gases

The mold itself may supply large volumes of gases. Such gases include steam from green-sand, air held in the pores of the sand, carbonic oxides from the ignition of carbonaceous mold facing materials and core compounds, hydrocarbons from the decomposition of organic bonding compounds, and gases from the interstices of chills. Some of the gas may be dis-



Evaporator End Plate—Internal View—Showing Gates and Risers. Note size of standard 2 in. test bar at right of casting. (Required hydrostatic test—50 lbs. per sq. in.)

solved but most of it remains insoluble and in the form of distinct bubbles. If the metal is too viscous to allow the gas to escape, then some gas will be retained. This gas will cause blowholes in the resultant casting which will usually be irregularly distributed and often confined to the surface[22]. The prevention of trouble which arises on account of mold gases belongs properly to the study of foundry technique. The moisture content and tamper of the sand in the mold should be carefully regulated and sometimes the type of grain as well. Also cores must be well baked and thoroughly vented to permit rapid exodus of the gases.

Metallic Oxides

This condition, consisting for the most part of occluded *tin* oxide, is commonly called oxidation. The presence of tin oxide in zinc bronze is definitely harmful. The fracture has a reddish chocolate appearance and almost always indicates low physical properties and porosity. The mechanism of the latter probably is that metallic oxides in contact with dry sand cores produce oxides of carbon which are entrapped in the freezing metal around the core causing a ring of holes in the casting. This trouble is encountered more frequently in bronzes of higher lead content[27]. To avoid oxidation, the use of chips and scrap must be prohibited as well as excessive heating and soaking of the melt in the furnace. However, the chief remedy is the proper use of the deoxidizing agents zinc and phosphorus.

This alloy may be melted in the usual types of bronze melting furnaces. If ideal quality or the highest mechanical properties are consistently required, melting in crucibles placed in a natural draft pit type furnace is recommended. In the crucible process ingot copper is first melted and protected from oxidation by a covering of crushed charcoal. Although zinc and tin are both fairly good deoxidizers of copper, it is advisable when making up gun metals to deoxidize the copper with zinc. This procedure is followed because zinc oxide readily floats off in the slag while tin oxide if once formed is difficult to remove because of its tendency to ball up and thus escape the reducing action of subsequent additions of zinc or phosphorus[30]. Nickel in the form of 50 per cent cupro nickel is added together with the zinc; followed, after a proper interval, by the tin while the lead additions, if any, are delayed until just before the crucible is ready to withdraw from the pit. Before pouring, the melt is again deoxidized, this time with phosphorus and vigorously stirred with a graphite rod. Phosphorus is usually added as a copper phosphorus alloy containing 10-15 per cent phosphorus in which it exists as the compound Cu_3P.

Furnace and Melting Gases

Another type of gases is dissolved or combined with the bronze. They originate either in the raw metal used for preparing the alloy or are picked up from the furnace atmosphere during melting. Excessive heating or soaking of the metal will serve to aggravate the condition.

It has been fairly clearly established that dissolved or occluded gases are more soluble in the molten than in the solid metal and that in both the solid and liquid the solubility falls with the temperature. The result is that during the cooling of a casting gases are likely to be liberated. Some of this gas will have the opportunity to escape through the liquid metal and free itself from the casting entirely, but if the volume of liberated gas is large or if the molten metal is viscous some of this gas, like mold gases, may remain entangled in the metal and appear in the castings as blow holes. Gas may be also liberated during the actual solidification of the metal[22].

There appears to be a critical rate of cooling for a given bronze above which the gases are not liberated, and by controlling the casting temperature (keep below 2300 deg. F.) or by casting in chill molds so that cooling is sufficiently rapid, sound castings free from gas bubbles may be normally obtained[22].

Also there is plenty of evidence that it is best to melt bronze in a slightly oxidizing atmosphere if unsound castings are to be avoided[16, 21]. The reason might be that it is not likely that the blowholes are formed by the liberation of oxygen, as the oxygen present in the metal is readily removed by the formation of metallic oxides. These oxides are in turn eliminated by use of the deoxidizers zinc and phosphorus. However, investigations show that a furnace atmosphere high in carbon monoxide, an essentially reducing atmosphere has a most deleterious effect on the soundness.

This covers in a brief way the chief causes and remedies of gas porosity. One last caution—it should be remembered that in general, if the metal is poured too cold, it will be too sluggish and viscous to liberate any gases involved.

Intercrystalline Shrinkage Porosity

A Function of the Freezing Range

H. S. PRIMROSE[3] concluded in 1910 that *soundness,* ultimate strength and degree of elongation depends upon the rate of solidification. This is still the opinion today[18, 33] when it is maintained that the fundamental cause of shrinkage porosity is slow or prolonged freezing with consequent sluggish feeding of sections. The reason for the difficulty encountered in avoiding such conditions in composition "G" is, primarily, its extremely wide freezing range of approximately 350 deg. F. (see Fig. 1).

The equilibrium diagram is of the solid solubility type and inasmuch as metallic solid solutions do not usually crystallize from a single center outward uniformly but grow in certain directions faster than in others, tree-like forms result known as dendrites. Since during the freezing process bronze contracts considerably, each dendrite occupies less volume than the liquid from which it is formed and consequently tends to leave a space around it. While any liquid metal is available it will flow into these spaces and make good the solidification contraction. If for any reason liquid metal is not available during the whole time of freezing then contraction cavities will be found in the resultant castings. It can be appreciated that, if the freezing covers a wide cooling range of temperature, then a considerable depth of metal from the cooling face of the casting will be freezing at the same time and the feeding liquid will have to traverse a long and tortuous maze of dendrites to fill up the last cavities[22, 34].

Gases may also be liberated during the actual solidification of the metal and play a part in causing intercrystalline porosity. According to Bolton and Weigand[21] the gas rejected in the crystal interstices during crystallization prevents feed back of the metal—causes shrinkage by preventing feed through back pressure. Most of the controversies concerning gas effects center around this type of reaction. Dews[22] states that the cavities are formed primarily by contraction and while they may provide lodging places for liberated gases and may even be propagated by accumulated gases, they are not formed through any buffer action of the gases. In any event it is generally agreed that melting under a reducing atmosphere will aggravate intercrystalline shrinkage porosity even if it does not cause it. Further than this however the porosity may be treated very readily without considering gas liberations at all.

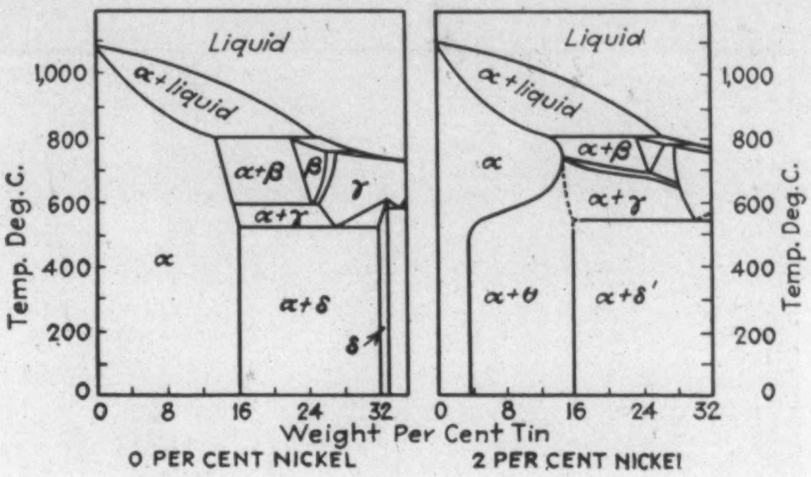
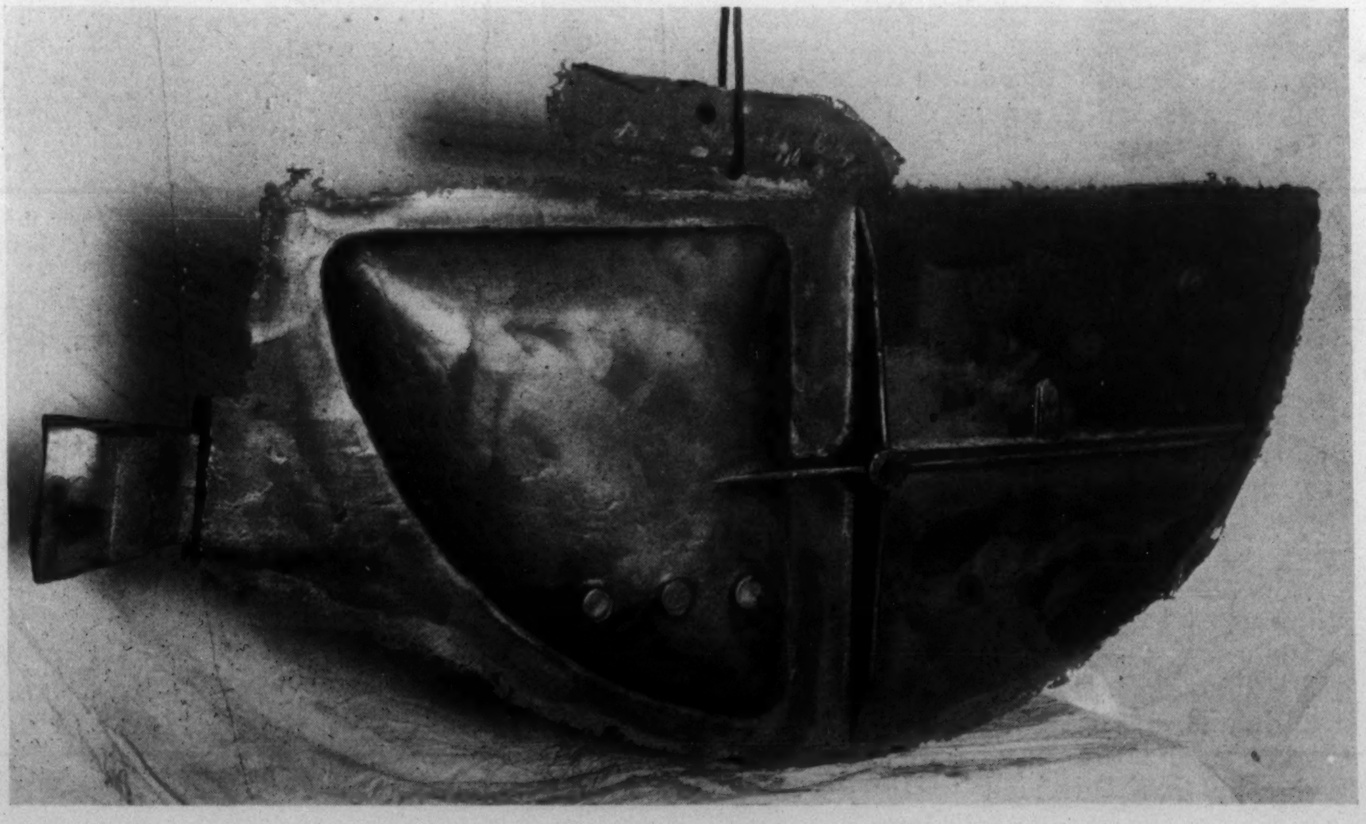


Fig. 1.

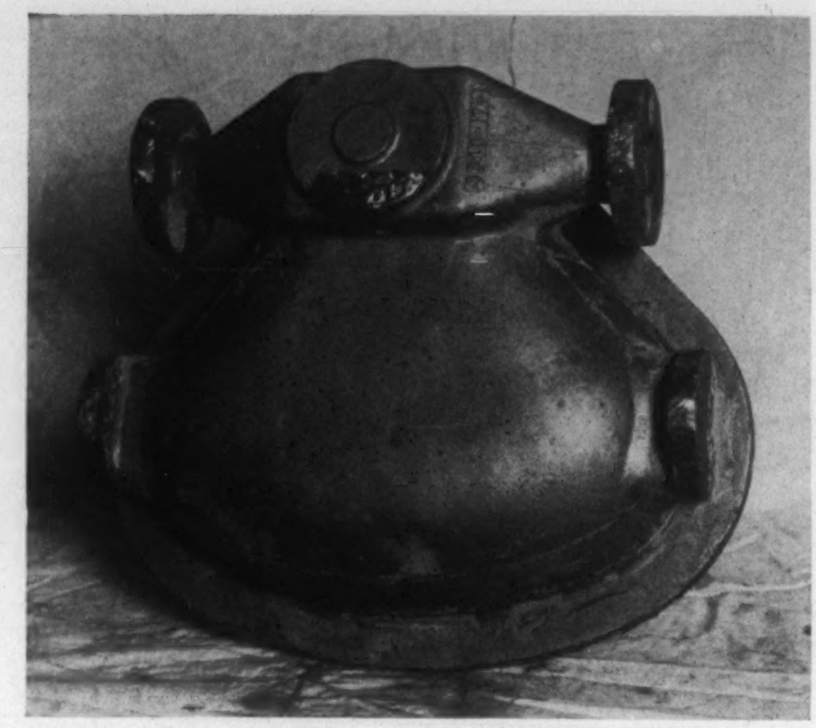
The unfavorable effect of the long freezing range of gun metal on the rate of solidification may be countered. Suitable design and careful foundry practice, including proper casting temperatures and a judicious choice of alloying elements, will increase the freezing rate and produce pressure-tight castings.

Casting Temperature

The casting temperature has, through its influence on the rate of solidification, a greater effect on the soundness of zinc bronze than any one other factor. This was first shown by Karr and Rawdon [6] and subsequently confirmed by Carpenter and Elam[8]. It is obvious that freezing will proceed faster with a low



Evaporator End Plate—External View—Showing Gates and Risers. (Required hydrostatic test—50 lbs. per sq. in.)



Feed Regulator Body for Evaporator—External View. The riser distribution is indicated by the shiny spots on the four flanges and on the boss in the center. (Required hydrostatic test—50 lbs. per sq. in.)

than with a high casting temperature which heats thoroughly the surrounding mold compelling slow cooling. Consequently, providing other factors are kept constant, the density of bronze increases and the grain size will be reduced as the casting temperature falls.

It is on the other hand equally detrimental to cast too low. The poor physical properties that accompany the very low casting temperatures are not however attributable to structural so much as to mechanical defects. This is due to the increased viscosity of the metal manifested in the form of entrapped oxide and gas and in improper feeding[11]. An exact temperature is not easily obtained as procedures and compositions vary from one foundry to another. Following on this to get the same quality in all castings the metal for large and thick castings should not be so highly heated when cast as that which is used for much thinner work. The molds should be arranged so that those of light nature are cast first with hot metal.

The temperatures recommended[6, 8, 28] for pouring 88-8-4 fall in the range 1950 to 2200 deg. F. and under no circumstances exceed 2300 deg. F. The temperature should always be determined before the bronze is poured in order to be certain that it is within the safety range. This involves the use of a pyrometer (portable millivoltmeter is most suitable) which can be depended on to give reliable readings. To overcome the effect of the naturally wide freezing range of composition "G", advantage must be taken of the counteracting effect of these low casting temperatures.

Design and Foundry Manipulation

The surface of composition "G", chilled by the mold, is fine equiaxed grained and pressure tight. It is necessary to retain this surface as it offers another legitimate means of circumventing the alloy's liability to shrinkage porosity. The design therefore should maintain a cast finish for pressure castings when possible and a minimum allowance for machine finish when machining is necessary. The avoidance of right angle bends and the coring of heavy bosses are details of design which aid materially in the production of pressure castings. Incidentally, apart from the finely divided porosities produced by the gradual closing of connecting channels, there are the large cavities or so called foundry shrinkage which are to a great extent caused by incorrect construction of the molds and incorrect spacing of heavy and light sections. The ideal casting should be of uniform thickness throughout while ample fillets should always be provided when it is necessary to run heavy sections into light. A study of the foundry problems involved in the manufacture of pressure castings, especially those of intricate design should begin on the drawing board.

Accurate cores and molding and well-designed exact pattern equipment, are of major importance for this type of work to maintain the features studied in design, as incorrect shrinkage allowance, excessive machine finish or inaccurately fitting cores may defeat the very object sought in the original design. Selection of the type and size of gates should be given serious consideration in order to permit the entrance of metal to mold with the least amount of agitation and to distribute metal as far as possible to permit uniform rate of cooling in various sections.

Chilling of heavy bosses may be necessary so as to aid in securing a uniform rate of cooling. In some instances it is advisable to eliminate risers which would normally be used on non-pressure castings and to resort to chills. The riser not only keeps that section of the casting liquid for a longer period, thus increasing its grain size, but its subsequent removal also destroys the skin effect. Where it is impossible to avoid a certain amount of heavy machining, chilling may be employed to augment the dense metal at the surface. Too much emphasis cannot be placed upon the importance of proper machine finish allowance[26].

The Effect of Alloying Elements

Addition of alloying elements, even in comparatively small quantities, will modify the freezing range in one or the other direction or otherwise change the rate of cooling. The importance of this cannot be too highly stressed for very often a proper composition alone means the difference between a sound and a porous casting. The range of elements that best temper zinc bronzes' wide freezing range is similar to the range for composition "G" recommended by Fawcett[31].

Desired:	Cu	Sn	Zn	Ni	Pb
	88	8	4	0.75	0.30
Permissible:					
Cu	87 to 89	Ni	0.75 max.	S	0.05 max.
Sn	9.5 to 10.5	Pb	0.30 max.	Si	0.02 max.
or	7.5 to 8.5	Sb	0.25 max.	Al	None
Zn	1.5 to 2.5	Fe	0.10 max.		
or	3.5 to 4.5	P	0.05 max.		

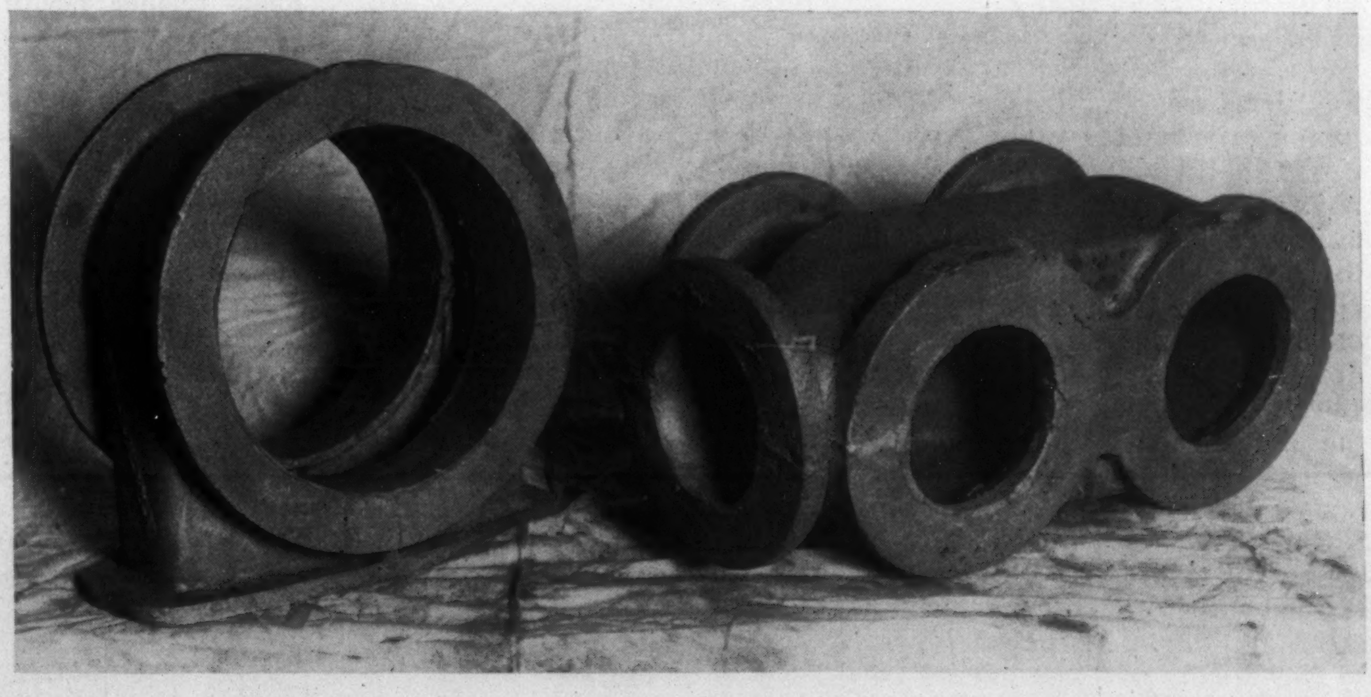
Nickel especially, zinc and lead when used discreetly, will increase the density and soundness. Within limits tin, iron, antimony, and sulphur have no appreciable effect. However, the presence of aluminum and silicon must be absolutely prohibited. The tin content is regulated by the physical and corrosion resisting requirements of the alloy, while the iron, antimony, and sulphur are present only as impurities.

NICKEL.—Small amounts of nickel exert the greatest influence upon the structure of composition "G". It produces a fine-grain, higher strength casting with dense and steam tight structure, which is naturally more resistant to corrosion and erosion than a bronze with a coarser structure. The addition of nickel in amounts from 0.5 to 1.5 per cent will increase the density although special attention to deoxidation appears to become necessary if the nickel content exceeds this. While the resistance of 88-8-4 to comparatively slight degrees of deformation as indicated by proportional limit and yield point increases continuously with a rise in nickel content up to at least 5 per cent, breaking strength and elongation reach their best proportions at about 1.5 per cent nickel content[28]. This quickening of the rate of cooling and subsequent increase in density and strength on addition of small percentages of nickel is all accomplished by some peculiar unexplained property of the element and notwithstanding an uncertain effect on the freezing range.

Nickel quite generally raises the melting point of bronzes. A recent laboratory study shows the increase in liquidus temperature to be about 12 deg. F. per 1 per cent nickel content if nickel replaces copper or 30 deg. F. per 1 per cent if nickel replaces tin[28]. However, the results of Pilling and Kihlgren[29] indicate it raises the solidus at just about the same rate that it raises the liquidus with little or no effect on the freezing range. Nickel has also been found to increase the fluidity of bronzes and therefore the raising of the freezing range does not affect the pouring temperature. Providing other factors are correct there should be no necessity for looking to a greater content than 0.75 per cent to produce a sound close-grained casting. This amount will also produce a uniform distribution of lead.

It might be well to just mention here that on the addition of nickel to composition "G", a change also takes place in the copper-tin alpha phase boundary and the alloy is rendered age hardenable.

ZINC.—Zinc exerts no effect on the freezing range but is of importance as it increases the fluidity of the metal and facilitates casting at low temperatures. It also acts as a deoxidizer upon any oxide of copper present. The excess zinc goes into solution and has the same effect upon the constitution as the addition of tin. Guillet[2] determined experimentally that tin has a coefficient of equivalence of two with respect to zinc as unity.



(Left): Ventilation Valve Body, required hydrostatic test, 13 lbs. per sq. in. (Right): Manifold Body for Feed Suction, required hydrostatic test, 150 lbs. per sq. in. (In general the risers lead from the flanges).

LEAD.—The chief effect of the presence of lead is mechanical. It improves the machinability and will also prevent checks or cracks at the junction of a boss and the body of the casting. In a case of this kind it would aid in pressure tightness. Furthermore that portion of the alloy containing lead is the last to solidify and therefore aids in filling the crevices caused by the internal shrinkage. The amount necessary to bring out the best machining qualities with a minimum loss in physical properties is only 0.50 per cent[31]. This figure is often lowered to 0.30 per cent to prevent pyramiding of scrap. In general lead detracts from strength and hardness because of the facility with which fracture passes thru these globules.

ANTIMONY.—There is apparently no effect on the soundness of sand cast gun metal containing up to 1.5 per cent of this impurity though there is reported an increase in hardness and tensile strength [9, 10].

PHOSPHORUS.—Phosphorus content should be kept low because of its tendency to increase the freezing range by depressing the temperatures at which freezing is completed without a proportional lowering of the temperature at which freezing commences [22, 31]. It is common practice to add a little phosphorus to gun metal for the purpose of deoxidizing the metal. Additions of less than 0.05 per cent are rarely harmful but do little good unless they represent a distinct excess after reduction of oxides has been accomplished[23]. Above 0.05 per cent causes the appearance of the free Cu_3P and a reduction in the mechanical properties.

SILICON.—Silicon apparently goes into solution and alters markedly the crystallization characteristics. Very small percentages in bronzes containing copper, tin, zinc, and lead have a tendency to produce a coarse dendritic structure with intercrystalline fissures which cause castings to be weak and porous. Bolton and Weigand[21] found that 0.02 per cent silicon was not dangerous though 0.04 per cent was very.

ALUMINUM.—The presence of aluminum should be carefully guarded against for, in a manner similar to silicon, it alters crystallization. Aluminum increases the grain size and is the cause for a high percentage of leakers, especially in castings of thin section[31]. It does its greatest damage when added to alloys containing lead.

Annealing For Pressure Tightness

IT may so happen that the design or the foundry practice was not quite as it should be or a particularly difficult and intricate part is encountered and a porous casting results. This fact is not discovered however until the machining has been entirely completed and the piece has been subjected to hydrostatic pressure. Rather than lose the money spent on machining and casting and risk a recast which in turn might be equally as bad, the piece may be made sound by annealing (heating to just below the solidus). This refers of course only to castings afflicted with intercrystalline shrinkage porosity.

Besides closing the shrinkage pores annealing will relieve casting strains[15] and effect diffusion of the as-cast dendritic structure. In its annealed state the microscopic examination shows the metal to have been completely crystallized into the characteristic polyhedral crystals of alpha bronze. To the non-ferrous metallurgist a homogeneous solid solution, such as is produced by annealing, indicates properties far superior to a dendritic structure. The elongation and reduction of area are substantially raised though the strength, yield point and hardness are affected but little. The improvement in the physical properties and the relief of internal stress alone, capable of being brought about by annealing, has not resulted in the process being brought into standard industrial use.

Composition: 88-8-4	Average of Three Specimens (0.505 in. bars)				
	Cast	Annealed 1000 deg. F. 2 hrs.	Annealed 1300 deg. F. 2 hrs.	Annealed 1400 deg. F. 2 hrs.	Quenched 1300 deg. F. 2 hrs.
Max. Load, Lbs. per sq. in.	45,100	41,930	43,450	44,900	46,600
Elong. (2") %	42	32	50	46	62
R. A. (approx.) %	40	34	40	42	44
Dendritic Structure	Medium mesh	Some diffusion	Disappeared except for faint shadows	Disappeared	Disappeared except for faint shadows

Fig. 2. Summary of Experiments on Heat Treatment.

Several reasons might be given for this, the chief being that, by proper control of process and materials, a satisfactory margin over specifications could always be obtained without recourse to annealing. There was also the fear, though not warranted, that treatment at a temperature of about 1300 deg. F., would cause large castings to sag.

H. S. and J. S. Primrose[4] referring to 88-10-2, see Fig. 3, concluded that annealing of the metal for 30 min. increases very considerably its strength and elongation, the most satisfactory results being at 700 deg. C. (1292 deg. F.). The homogeneity and other physical properties of the metal are correspondingly improved but particularly the ability of the castings to withstand hydraulic pressure. Some additional experiments by H. S. Primrose[5] confirmed the fact that only an almost inappreciable change in structure was produced by any annealing conducted at a temperature much below 700 deg. C. Karr and Rawdon [6, 7] studied the alloy 88-10-2 in great detail and found that heat treatment is productive of increased ductility and tensile strength when annealed in the range 700 to 800 deg. C. (1292 to 1472 deg. F.) which is in accord with the results of Primrose. Comstock further verified the Primrose conclusions that annealing at about 700 deg. C. is beneficial[12].

The results of experiments conducted with the alloy 88-8-4, see Figs. 2 and 3, agree quite well as would be expected with the previous work on the slightly different alloy 88-10-2. It was found that an anneal in the range 1300 to 1450 deg. F. will give pressure tightness with a perceptible increase in ductility over the as-cast and a definite increase in physical properties over an anneal at 1000 deg. F. Diffusion will take place only very slowly and in consequence prolonged periods of annealing are necessary. In the case of large sand castings, the removal of dendrites is not technically practicable. The treatment therefore necessary to obtain the best results is determined by the size and condition of the casting. The recommended practice is one hour for each linear inch of wall thickness at 1400 deg. F. though the heating may be for a shorter time at a higher temperature or for a longer time at a lower temperature.

It is evident that such treatment tends to protect from hydraulic failure porous castings suffering from intercrystalline shrinkage unsoundness by closing the grain and lessening the interstices or voids between the crystals. Though the mass is compacted to an extent which renders it pressure tight, the actual mechanism is obscure. This closing of microscopic pores may be the result of the dynamic equilibrium of the molecules and their constant effort to adjust themselves, one to another, to assume the form of greatest physical stability. The atoms in a crystal lattice are in a state of thermal vibration around their average positions at all temperatures above the absolute zero—the higher the temperature, the greater the amplitude and the higher the frequency of the vibrations. Still another opinion advanced is that the voids might be closed through an increase in volume of the matrix taking place concurrently with the absorption of the dendritic structure. That is, the homogenized structure may occupy greater volume than the cast structure.

Rapid Cooling Following Annealing

Karr and Rawdon[6, 7] found that in quenched bars of 88-10-2 superior results, slightly better than the annealed, were obtained in the temperature range from 600 to 700 deg. C. C. F. Smart[13] studied the effect of annealing 88-10-2 followed by different rates of cooling and in particular the effect of quenching. He recommended whenever possible a quench followed

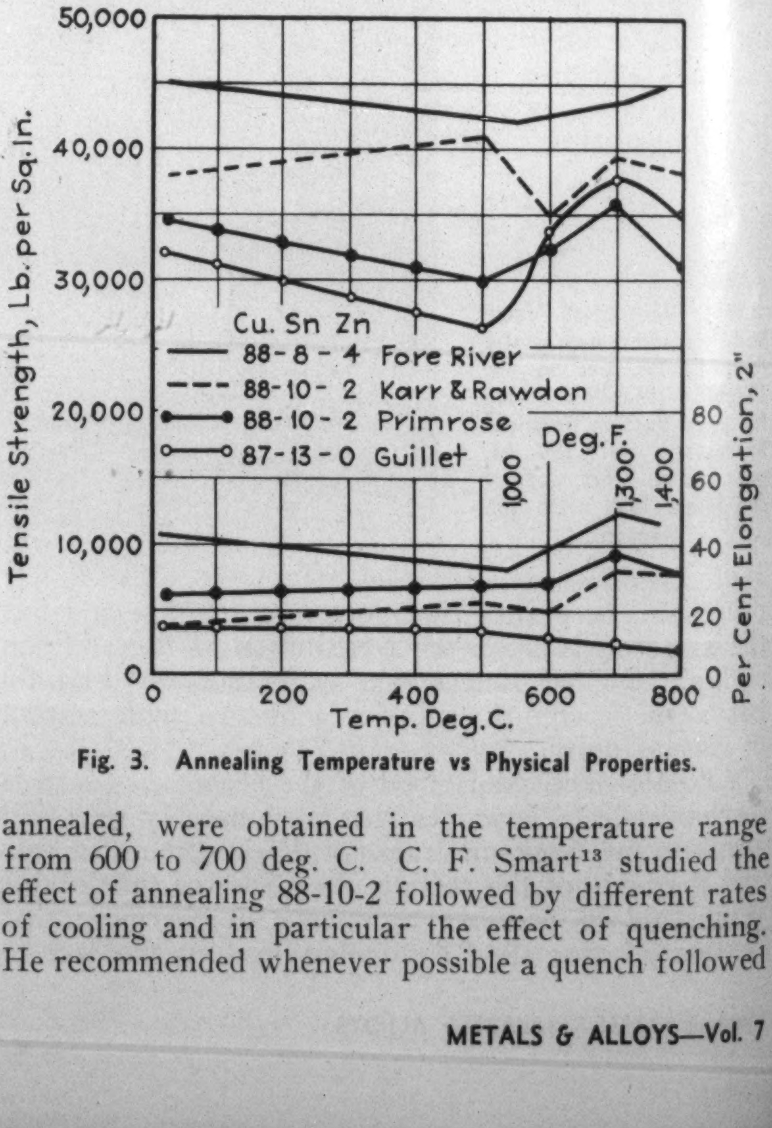
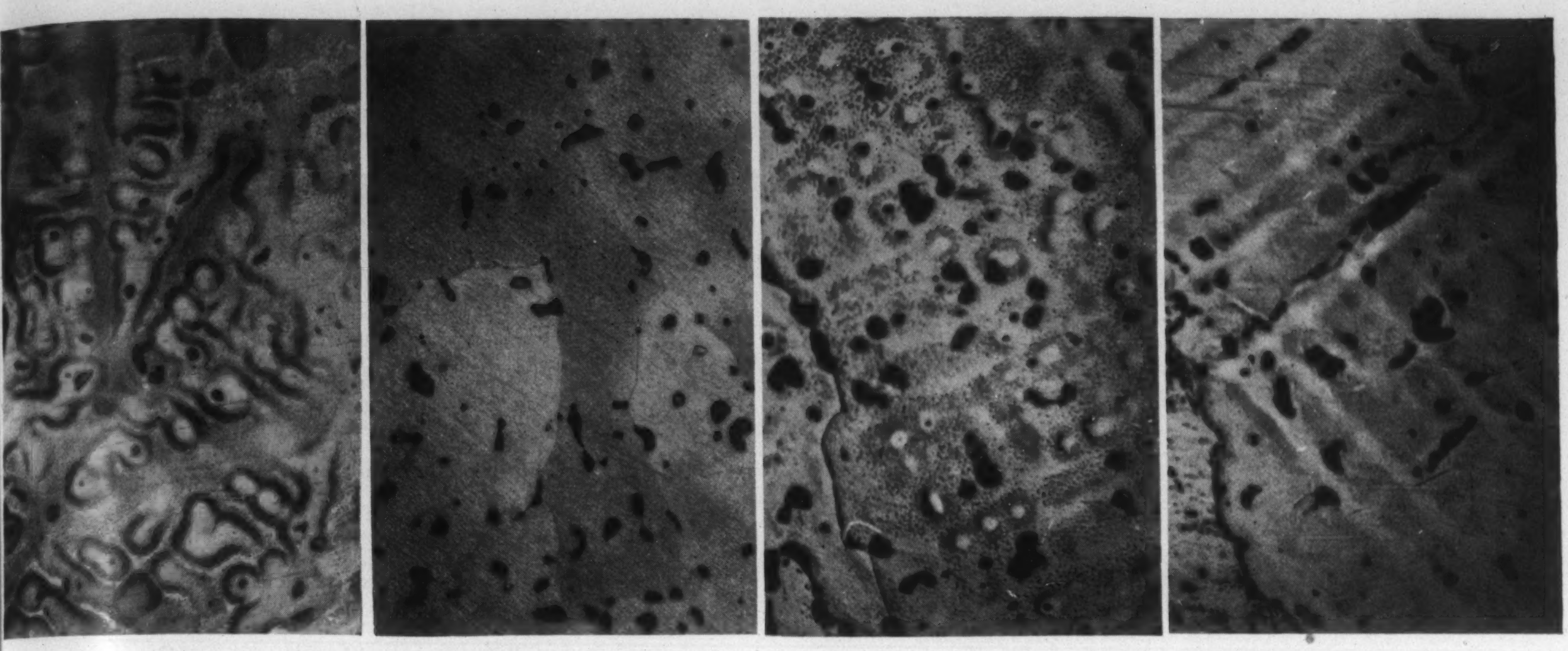


Fig. 3. Annealing Temperature vs Physical Properties.



As Cast

Annealed 2 Hrs. 1000 deg. F.

Annealed 2 Hrs. 1400 Deg. F.

Annealed 2 Hrs. 1300 Deg. F.

Fig. 4. Photomicrographs of Representative As Cast and Annealed Composition "G" (88-8-4) Showing the Dendritic Structure in Various Stages of Diffusion. Since the bronze is lead free, the black spots indicate contraction cavities entirely. Attention is called to the absence of the delta constituent which is so prevalent in 88-10-2. Etched with MH_4OH-H_2O_2. Magnification 50 diameters.

by an anneal at a lower temperature to draw the strain out of the casting and maintained furthermore that air cooling gave better results than furnace cooling. The cause of the improvement attained by rapid cooling was first suggested by Price, Grant and Phillips[19] and later elaborated by Pilling and Kihlgren[28, 29]. They explained that nickel causes a change to take place in the solubility curve and although the solubility at higher temperatures is little altered, that at lower temperatures is lowered, see Fig. 1. Thus the bronze may by suitable heat treatment be age hardened, due to the precipitation of a dispersed constituent. The heat treatment consists usually of annealing and quenching from about 1400 deg. F.; although air cooling will suffice for small castings followed by tempering at about 600 deg. F. There is also the possibility that an iron-rich compound would be precipitated by a 1400 deg. F. heat treatment.

Nickel is completely miscible in alpha-range copper-zinc alloys even to the complete replacement of the copper content by nickel. That is to say, the presence of nickel leads to the development of no new constituent and the zinc content marking the first appearance of the beta phase is but scarcely changed by the presence of even 20 or 30 per cent of nickel[20].

On the other hand the alpha range of the copper-tin alloys is sharply restricted by nickel. If the tin exceeds that of the alpha boundary, insoluble nuclei are formed and an excess phase is precipitated. The solubility of tin in the alpha phase of the copper-tin system decreases between 590 and 500 deg. C. and then remains constant to room temperature. The solubility of tin in the alpha phase starts to decrease at the nickel content at which the alpha comes in equilibrium with the theta phase which varies between about 0.5 and 3.5 per cent nickel.

The precipitated phase has been designated as theta. The theta constituent is clear and has a blue color on etching with acid ferric chloride. It has a nodular and needle-like form and, while most of it occurs in the alpha, some of it also locates at the grain boundaries. The theta phase is thought to be either the compound Ni_4Sn or Ni_3Sn of the nickel-tin system reported by Voss or, what is more probable, one of those compounds containing copper in solid solution.

The microstructure depends upon the rate of cooling through the temperature range in which the solubility of tin decreases in the alpha range. When an alloy is cooled fairly rapidly through this temperature range, the theta constituent is precipitated in a very finely divided state in the alpha. After etching this mixture has a dark appearance. When these alloys are cooled at a much slower rate, the theta phase coalesces into large grains and the alpha matrix is clear after etching[32].

Experiments conducted with 88-8-4, see Fig. 2, indicate that the physical properties of the annealed bronze are improved by quenching though not markedly. This is explained by the small quantity of hardening elements present including a maximum nickel content of only 0.75 per cent. Attention is directed to the excellent ductility associated with high tensile strength and proportional limit.

There is, however, considerable danger from cracking, in quenching castings especially if the castings are large; not as much from the effect of the quenching medium as from the handling of heavy sections. It is obvious, however, that if following an anneal, a quench is not practical, an air cool or even the mere opening of the furnace door would be beneficial[13].

Interpretation of Fractured Specimens

A WORD on the appearance of the surface of the fractured specimen in its relation to the soundness of bronze might be in order. The relative orientation of the interior dendritic structure of neighboring crystals follow no definite plan; this is shown by microscopic observation of the specimen. Those crystals which are most favorably oriented will be stretched beyond the elastic limit first; they most probably are those whose principal axis of orientation coincides with the direction of the applied stress. The roughening or "crinkling" of the surface of the tensile bar shows that different crystals are affected unevenly. In other words the mechanical properties of the individual crystals are not the same in all directions[6], [22]. Thus a fine grained sound structure would be expected to exhibit a fine crinkle while a large grained porous bar, a very coarse crinkle.

Conclusions

SINCE the purpose of this paper is merely to compile and interpret, there has been no logical development of any new conception. In drawing conclusions we are dealing with principles which are already known.

I. Precautions to Minimize Gas Porosity:

A. Melting Practice—

1. Always employ pure ingot metal and never chips or scrap.
2. A proper use of deoxidants is important by melting copper first, deoxidizing with zinc and then adding the tin and finally deoxidizing with phosphorus.
3. Maintain slightly oxidizing furnace atmosphere. A reducing atmosphere is definitely harmful to pressure castings both as regards gas porosity and inter-crystalline shrinkage porosity.
4. Employ proper pouring temperatures 1950 to 2200 deg. F. (keep below 2300 deg. F.) so that cooling is sufficiently rapid to retain furnace and melting gases in solution. On the other hand, if the metal is poured too cold, it will be too sluggish to liberate the gases.

B. Molding Technique—

1. To minimize mold gases, carefully regulate the grain size, moisture content and tamper of the sand. In addition the cores should be well baked and thoroughly vented.

II. Precautions to Minimize Intercrystalline Shrinkage Unsoundness:

A. Design—

1. The design should maintain a cast finish for pressure castings when possible and a minimum allowance for machine finish.
2. It is desirable to have the thickness throughout the casting as uniform as possible and to employ generous fillets.

B. Foundry Practice—

1. Employ medium to low casting temperature (1950 to 2200 deg. F.) to maintain as short a freezing range as possible. In general the larger the casting the lower the temperature.
2. Judicious use of nickel (0.75% max.) to reduce normal grain size and of lead (0.30% max.) to prevent checks and cracks, aids in pressure tightness.
3. Phosphorus content should be kept low (0.05% max.) because of its tendency to increase the freezing range and to reduce the mechanical properties.
4. There must be absolute prevention of aluminum and silicon contamination which are fatal to castings requiring pressure tests.

C. Heat Treatment—

1. For applications not requiring pressure tightness heat treatment of gun metal probably should not be adopted industrially, the reason being that a satisfactory margin over specifications could always be obtained without recourse to annealing.
2. All pressure castings may be relieved of strains, improved both in structure and properties and furthermore their soundness assured by annealing.
3. Castings that exhibit shrinkage unsoundness on subjection to hydrostatic test may be made pressure tight by annealing.
4. The optimum heat treatment is an anneal of one hour for each linear inch of wall thickness at 1400 deg. F., though the heating may be for a shorter time at a higher temperature or for a longer time at a lower temperature, with rapid cooling whenever possible. Although the quantity of hardening elements present is not great, an air cool or even the mere opening of the furnace door will improve the physical properties of the annealed bronze.

Acknowledgement

The writer is indebted to Paul Ffield, materials engineer, at the Fore River Plant for his valuable comments. Appreciation is also expressed to the officials of the Bethlehem Shipbuilding Corp. Ltd. for permission to publish the data contained in this paper.

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Plating Equipment— Materials of Construction

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One cannot dispute the affirmation that a plating room and the equipment in it should be so constructed that the total of operation write-off or depreciation, and maintenance should be a minimum over a period of years. Unfortunately, many plants have grown like Topsy, and equipment has been added on the basis of first cost rather than on the basis of final cost. The purpose of this article is to point out some fundamental considerations which merit attention.

Since this article is concerned primarily with materials of construction, no attention will be given to electrical generating equipment nor considerations involved in its use, interesting and profitable though such considerations may be. It should be sufficient here to categorically state that generating equipment should be close to the point where the power is to be used, but should be separated from the plating room by an air-tight partition. Provision should then be made to furnish adequate ventilation of the generator room with fresh cool air. If the generating equipment is in the same room as the plating equipment, it ordinarily suffers undue depreciation from inevitable exposure to corrosive fumes from the plating operations. If the generating equipment is in the same room, it also has the further disadvantage of unnecessarily heating the plating room in the summer time, thus adding to the difficulty of maintaining desirable working conditions.

The Building

The *floors* of most plating rooms are ordinarily made of concrete. A more desirable but more expensive construction would be a floor of concrete over which is laid a floor of thoroughly vitrified brick, such as standard *paving* brick set in asphalt with cracks perhaps one-quarter to one-half inch wide between the bricks. These cracks should then be filled with asphalt to about one-half inch from the surface. Proper consideration should be given to gutters and slope of the floor so as to provide good drainage. The construction mentioned, of course, provides a small gutter every few inches over the entire surface of the floor.

On the other hand, these may fill up with dirt if the plant supervision is "sloppy" and if the floors are not kept well washed. To be quite practical, however, it must be admitted that the less expensive concrete floors are ordinarily satisfactory. The concrete floor, particularly around acid tanks, should be well coated with hot asphalt to insure durability of the surface. Even painting with asphalt paint is better than leaving the concrete bare.

Working floors or *platforms* between the tanks are ordinarily made of wood. If these are subjected to the dripping of chromic acid, they are relatively short lived. If they are subjected to the occasional spillage or overflow of cleaner solution, they are likewise quickly deteriorated and may become quite slippery, presenting a hazardous footing to the operators. In such locations steel floors, such as standard subway gratings, would be superior. Around acid tanks, however, the iron subway grating would be more readily destroyed by corrosion. Working platforms of wood are quickly put together with steel nails and these are, of course, likewise readily attacked by acids.

An arrangement which has been favored by the author involves the provision of angle irons on the plating tanks at a level such that they may serve as the foundation for the working platform. With a little ingenuity in planning the platform, it is then possible to build it so that the platform does not depend primarily for its strength or rigidity upon the nails employed to hold it together. Copper nails, or even better, Monel nails, though more expensive than steel nails, are justified from the standpoint of greater permanence and reduced cost of maintenance. The type of construction suggested above has the marked advantage of clearing the floor of supporting posts, thus making it possible to keep the floor under the working platform washed down and clean.

If the *building* is of steel construction, i. e., constructed with steel columns and roof supports, these should be given a bonderizing or other protective coating before they are put into place. Steel sash, for example, could profitably be heavily galvanized before erection. The steam which is inevitably liberated in a plating room is most destructive to paint. Usually after failure of the paint, there follows a period of neglect, resulting in rusting of the steel. Thereafter it is next to impossible to obtain a satisfactory painting job without first sand-blasting the steel, and the equipment already installed usually makes sand-blasting impractical. Where painting is employed, it appears that some of the newer paints such as a chlorinated rubber paint, are far more permanent than ordinary paints.

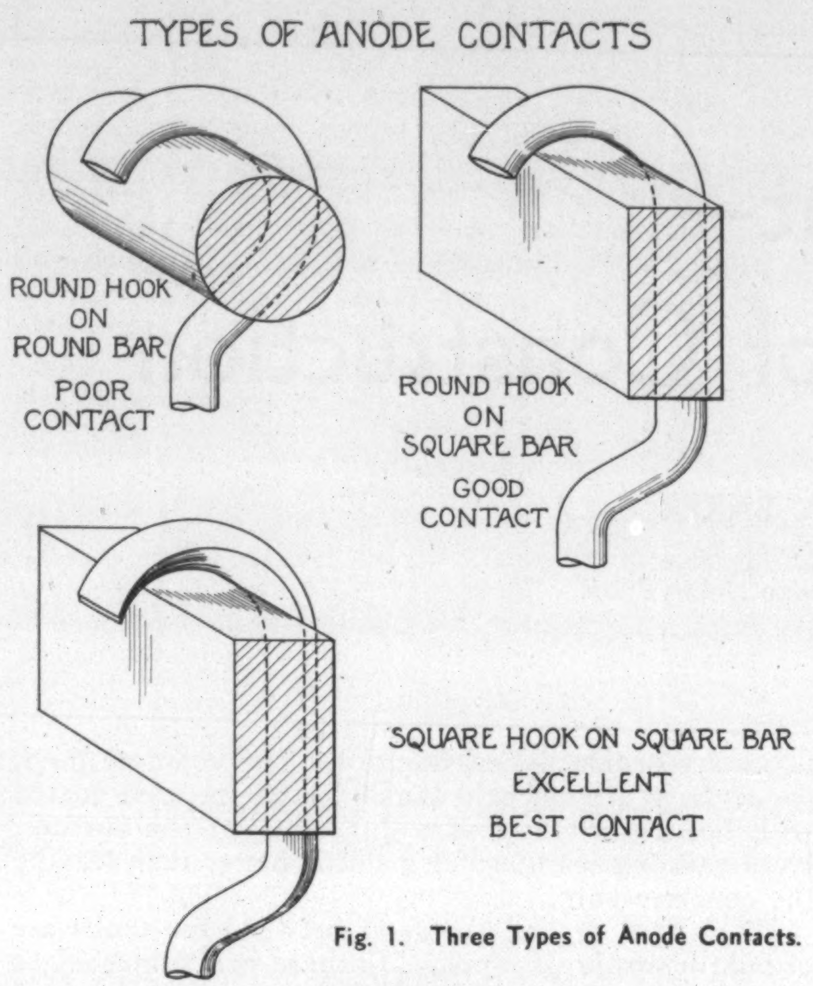

Fig. 1. Three Types of Anode Contacts.

Equipment

Materials for the construction will be considered under the following heads:

1. Structural work for conveyors.
2. Bus bars.
3. Cleaner tanks.
4. Acid Tanks.
5. Cyanide copper plating tanks.
6. Acid copper plating tanks.
7. Nickel plating tanks.
8. Chromium plating tanks.
9. Ventilating equipment.

Structural Work for Conveyors

Structural work for conveyors is almost universally steel, and should be given a bonderizing or other protective coating before erection, the same as the steel structural work of the building.

Bus Bars

Bus bars are usually of copper. Joints between lengths of copper bus bar may be either tinned and sweated together or the copper may be merely draw-filed at the joints. Either method is satisfactory if the workmanship is good. Bus bar clamps should be used in either case, and the bolts well tightened. Before plating operations are started, the erected copper bus bar should be given one or two coats of lacquer to preserve its initial appearance, as it will otherwise become more or less covered with green corrosion products during the passage of time.

Aluminum bus bar may be used in place of copper bus bar. If so, the cross section of the aluminum bus bar should be about 165 per cent of the cross section required for copper bus bar. The usual practice, therefore, would require about 1.65 sq. in. of aluminum bus bar per thousand amperes rated current carrying capacity. Obviously, smaller cross sections may be used for short runs and larger cross sections should be used for exceptionally long runs of bus bar.

The writer prefers rectangular bus bar to round bus bar for anode and cathode bars on the plating tanks. Likewise, anode hooks and the hooks on plating racks should be of square or rectangular cross section. Plating solution is inevitably splashed or dripped on the anode and cathode bars. This is drawn into the space between anode hooks and anode bars by capillary action, and in the case of round anode hooks on round anode bars will actually lift the anode from the bar as evaporation dries up the solution and leaves a deposit of the dry salts. With the knife edge or point contact the weight of the anode is carried by a very small area, giving such high unit pressures that the above action does not occur. Three types of anode contacts are shown in Fig. 1.

This was recognized many years ago by Floyd T. Taylor, who has repeatedly pointed out the disadvantage of round work bars and round hooks. He further pointed out that, if heating is obtained with sharp edged contacts, the remedy is not to increase the area of contact but rather the cross section of the metal behind the contact so as to provide more surface for the dissipation of heat.

Cleaner Tanks

Cleaner tanks should be made of steel with all joints lapped and welded inside and out. A convenient means of providing a drain and also an overflow for cleaner tanks is shown in Fig. 2. This consists of welding a threaded flange on the bottom of the tank near one corner and of setting into this a pipe which can be unscrewed from the top when it is desired to drain the tank. If the top of the pipe is hammered into the form of a square, a special tool may be readily made to fit this square to unscrew the pipe when the tank is to be emptied. If the liquid level becomes too great, it will, of course, overflow into this pipe.

Cleaning may be carried out either with or without the use of electric current. If electric current is not used or if cleaning is done with the work as the anode, there is no objection to using the tank as the other electrode, i. e., as the cathode. However, if the usual direct current cleaning is employed, it is not good practice to make the tank the anode. When steel has been made the anode for some time in an alkaline solution, particularly if the cleaning solution contains

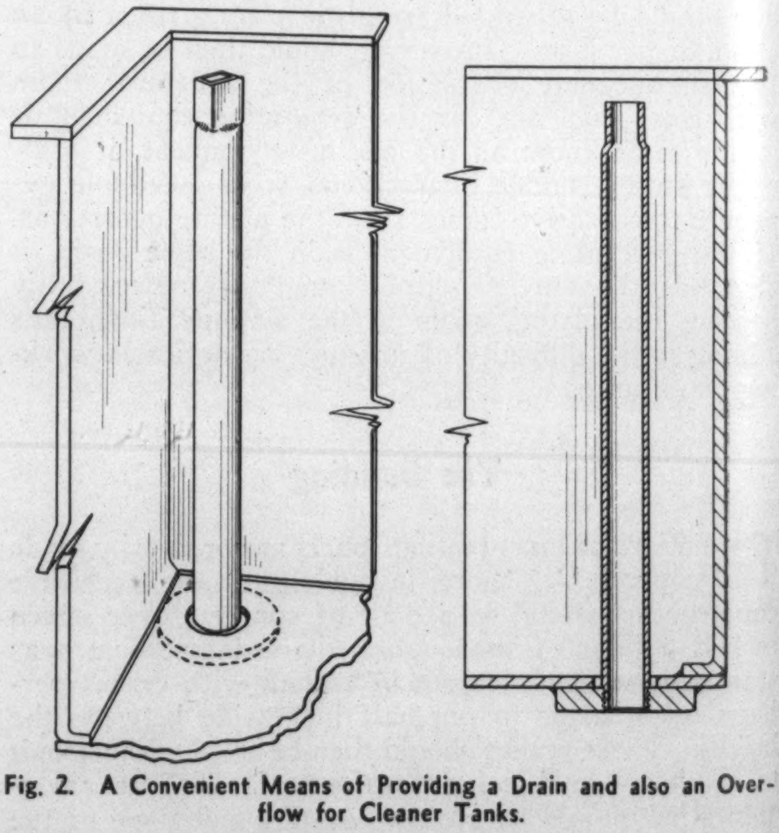

Fig. 2. A Convenient Means of Providing a Drain and also an Overflow for Cleaner Tanks.

sulphates or chlorides, even in low concentrations, it becomes scaled over, building up a considerable resistance to the passage of current. This in turn requires draining the tank and hammering or chipping the scale from the walls of the tank. Every time this is repeated, the tank walls become thinner and on sufficient repetition they will eventually fail. Therefore, separate anodes should be used. These should be nickel-coated, since nickel resists corrosion and scaling very much better than does steel. A good anode to use in this situation is nickel-clad steel coated with 0.05 in. of nickel, and of sufficient thickness so that the anodes will be stiff and not readily bent out of position. In place of nickel-clad steel, heavily plated ordinary steel may be and is frequently used. Pure nickel anodes would be excellent from the standpoint of use, but are not justified on the basis of cost.

Heating coils in cleaner tanks will be made of ordinary steel pipe, which may be joined together with standard fittings and return bends, and so designed that they can be readily removed for repairs.

Acid Tanks

Acid tanks in the plating room are usually provided to hold rather dilute solutions of either sulphuric or muriatic acid. Either lead-lined or rubber lined tanks may be employed, and the tanks themselves may be of either steel or wood. Lead-lined tanks have the disadvantage that corrosion of the lead takes place fairly rapidly at the solution level, particularly with muriatic acid. Lead linings have the advantage of being more readily applied to a wood tank and of being more readily repaired with facilities available in most plants.

Tanks lined with 3/16 in. of rubber by any of the well-established vulcanizing processes should be relatively permanent, as compared to two to four years' life for a lead lining. In the author's experience, rubber lined tanks usually fail, not from the inside, but by corrosion of steel from the outside.

It is necessary that provision be made so that acid being dragged out on the work removed from the tank will not drip or splash onto the outside of the tank. This can be taken care of to a large extent by means of a lead apron bridging the acid tank and the subsequent rinse tank. Before a rubber-lined or lead-lined steel acid tank is put into operation, the outside should be given at least two or three coats of heavy asphalt, applied hot. Ordinary painting is, at the most, ineffective, and after the tank is placed in position, it is impossible to paint the bottom of the tank and frequently impossible to paint both the ends and sides. It is a serious question as to whether it would not be an economy to have a rubber-lined tank covered externally with a lighter thickness of rubber, for example, 1/16 of an inch.

Drains should not be provided for acid tanks, but instead, when it is necessary to empty these, the acid should be pumped or siphoned from the tank. There are many who will contend that a wooden tank, heavily painted on the inside with asphalt, is entirely satisfactory for an acid dip tank, and is cheaper. This may be true, but the author's preference lies in the other direction.

Cyanide-Copper Plating Tanks

These should be of the same construction as cleaner tanks except that the author does not favor any outlet connections for plating tanks. Plating solutions are relatively expensive and if an outlet valve or connection is provided, there is too great an opportunity for some individual to make an expensive mistake.

Acid-Copper Plating Tanks

The author favors, for acid plating baths, rubber-lined steel tanks of the same construction as the acid tanks. Lead-lined tanks, while fairly satisfactory for acid dips, are rather short-lived when used for acid-copper plating baths, because the normal corrosion is always aided to some extent by electrolytic corrosion from current which passes from the lining to the work being plated. This can be avoided by connecting the tank lining as a cathode, but with the usual short distance between the anodes and the lining, this will result in a heavy flow of current between the copper anodes and the tank lining, which will soon become heavily copper plated. Control of current distribution is also much better in a tank having a non-conducting lining. The heating coils and/or cooling coils for an acid copper plating tank are ordinarily made of lead pipe and have a moderate life.

Nickel Plating Tanks

As regards material and type of construction, nickel plating tanks fall in the same category as acid copper plating tanks or acid tanks. Here again, it is especially advantageous to have a tank with a non-conducting lining. The coils used for heating and cooling are usually constructed of lead pipe and will have quite a long life if they are not so located as to serve as anodes. They should be kept at least ½ in. away from the lining so as not to cause heating and deterioration of the lining when steam is being passed into the coils. If they are close to the anodes, they should be completely screened by the anodes, because otherwise current will pass from anodes to the coils and then from the coils to the work at those points where the coils are not screened by the anodes. This will result in rather rapid corrosion of the coils in the unscreened or anodic portions.

In the case of large plating tanks, such as are used in full automatic plating tanks, many prefer to continuously pump solution from the tank, pass it through a heat interchanger and filter, and then back to the plating tank. Heat interchangers, which may be used for either heating or cooling as required, are available in Duriron, which is satisfactorily resistant to corrosion. This arrangement has not only the advantage of continuous circulation and filtration of solution, but also eliminates all of the problems arising from having heating surfaces in the tank exposed to both chemical and electrochemical corrosion.

Chromium Plating Tanks

For chromium plating, the author prefers a well-constructed steel tank lined with ¼ in. of 6 per cent antimonial lead. This antimony-lead alloy is fairly resistant to corrosion by chromic acid, but, even so, should be so connected that it will always act as an anode. It is particularly important that the tank lining be made the anode when solution is first introduced into the tank, so that the lining will become well covered with a protective coating of lead peroxide. The heating coils should be of extra heavy 6 per cent antimonial lead. The anodes should likewise be of antimonial lead, and they should be ¼ in. thick for tanks of moderate depth and 3/8 in. for tanks having a depth greater than 3 ft. The author prefers aluminum for both anode and cathode bus bars, as this

(Continued on page 296)

Practical Possibilities in

SPECTROGRAPHIC ANALYSIS

By GEORGE R. HARRISON

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WITH INCREASING RAPIDITY the metal industries are having forced on them the realization that the spectrograph is a necessity both in the laboratory and in the factory, because the spectrograph will not only save money but will make money.

Present Scope of the Art

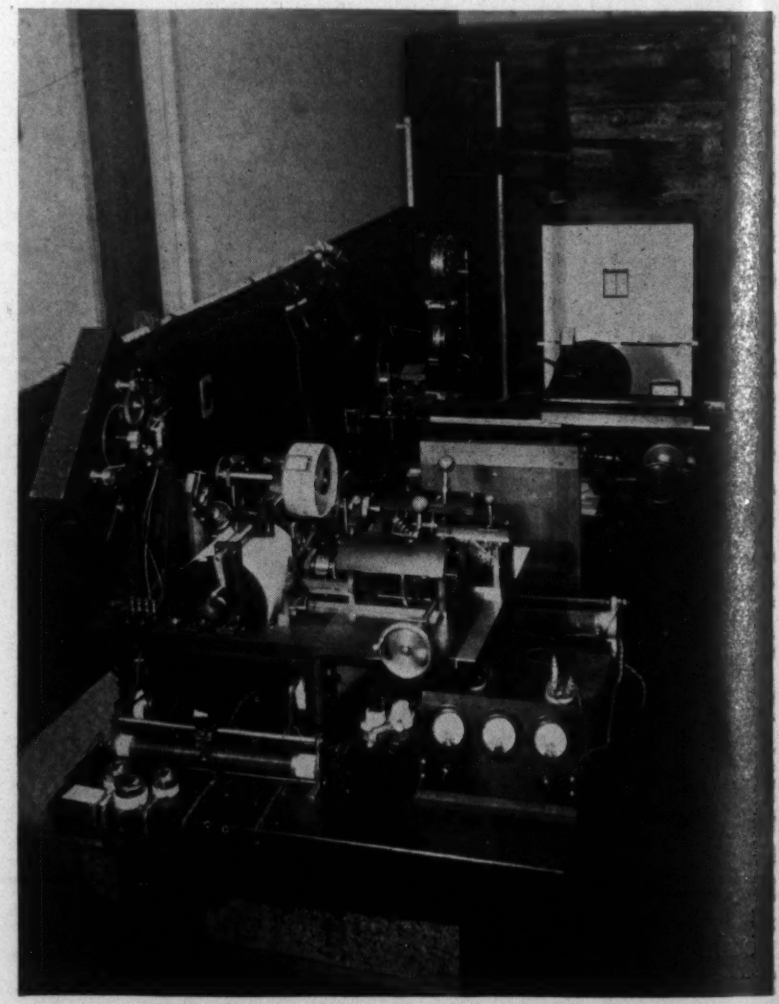
QUANTITATIVE determinations of all the important constituents of a melt can be carried out spectrographically in less than fifteen minutes (or five if need be), and every extra minute required for the determinations costs extra dollars through burned-out materials or improperly constituted alloys. If several tons or more of material are in the melt, the man in charge of that melt who uses old-fashioned methods is losing money for his company so fast that the cost of spectrographic equipment falls into insignificance.

It is easy to impress a chemist or a metallurgist with the advantages of the spectrographic technic, for he has had to guess and filter and simmer so much that he welcomes with open arms a method which for qualitatives will show him all metals present to 0.001 per cent or less in half an hour with no guess work, and for quantitatives will distinguish between 0.10 and 0.11 per cent or between 0.0010 and 0.0009 per cent with a minimum of fuss and bother. But it is not so easy to convince a vice-president that he should spend up to $5000 on a physicists' toy which, when he comes to look into the matter, he finds will not give analyses on such important things as carbon, oxygen, sulphur, and half a dozen others, and ignores entirely the negative radicals.

The usual and a sufficient answer to these objections is that it is unreasonable to expect a single instrument to accomplish everything, and that the spectrograph more than justifies itself in the analyses which it *can* make. Executives are being convinced by this argument in sufficient numbers to keep the manufacturers of spectrographs hard-pressed to keep up with the demand.

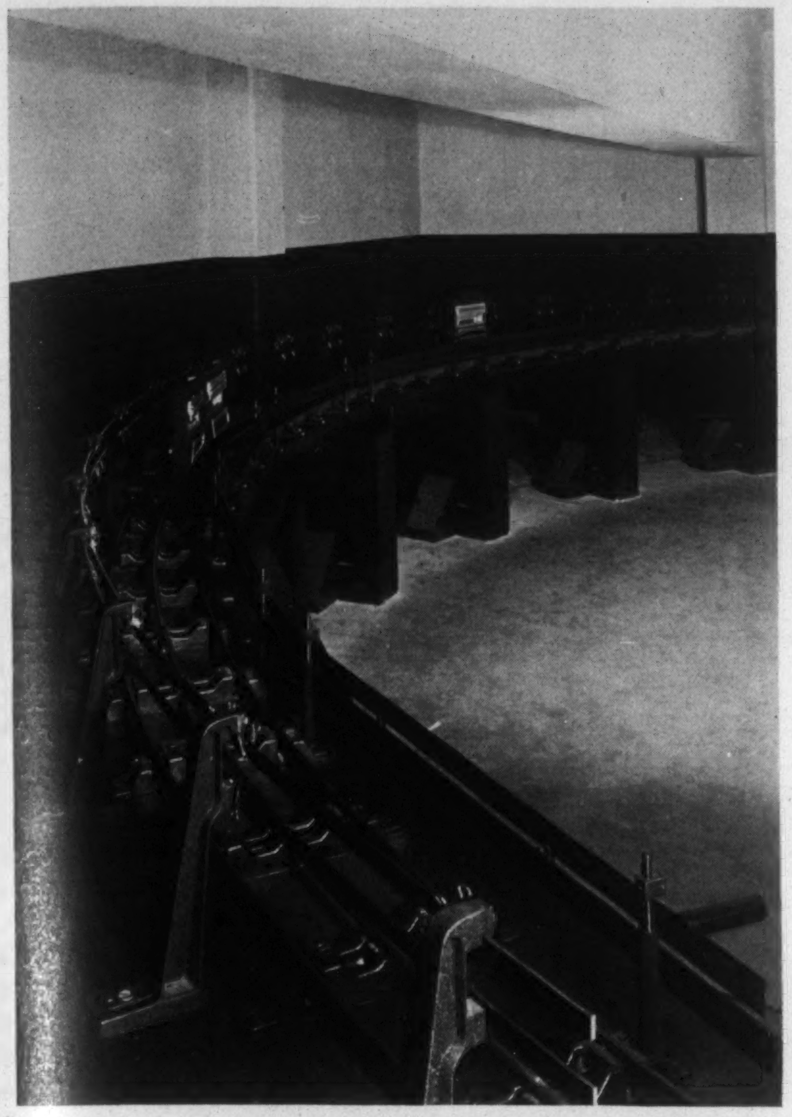
The purpose of the present paper is not to tell what spectrographic technic has done, but to outline what can be expected to be done with its aid through further development. It will be found that the spectrograph *can* be made to do carbon, oxygen, and sulphur analyses, that it *can* be made to indicate the presence of molecules and negative radicals, and measure them, and that gas analyses *can* be made spectrographically. For though not at present practicable, these things are all possible now in the laboratory, and a sufficiently strong demand for them will result in their practical development.

It should be appreciated that the spectroscopic analysis of materials is largely a by-product of the main development of spectroscopic methods. When the spectroscope was first developed in practical form, chemists used it for a number of years for qualitative analysis, discovered several new elements with it, and then practically dropped it. With the tremendously rapid advance of modern physics in the first quarter of the present century, the spectrograph became an important tool in determining the structures of atoms and molecules and in interpreting the relations between light and atoms.



A New Automatic Spectrum Comparator Recently Built at the Massachusetts Institute of Technology which Measures a Thousand Spectrum Lines a Minute, Computes Their Wavelengths and Records These to Seven Figures Instantaneously.

Until quite recently only a few scattered scientists have been at all concerned with the use of the spectrograph for analytical purposes. Now, as the determination of small quantities of elements present as impurities or alloying materials becomes of increasing importance, we find much of the technic necessary for accurate analyses ready to hand. Modern spectrographic analysis of materials is largely a by-product;



A Portion of the Track of the 25 Ft. Concave Grating Spectrum of the Spectroscopy Laboratory of the Massachusetts Institute of Technology. Photographic plates are clamped to the rear track to photograph a spectrum 40 ft. long.

it is one of those pleasant little side-profits which in research so often turn out to be of more importance than the main object.

Seventy Elements Determined Spectrographically

It is commonly considered that only seventy of the ninety known elements can be determined spectrographically both qualitatively and quantitatively. The metals are easiest to handle, particularly the lighter ones, and the concentration range in which the most accurate results are obtained is from 5 per cent down to 0.0005 per cent and below. Accuracy in qualitatives is unsurpassed; in quantitatives, precision is constantly improving. Several years ago it was generally believed that the spectrograph could determine the quantity of a given constituent to within 10 per cent at all concentrations; that is, it could tell the difference between 10 and 11 per cent, and between 0.0010 and 0.0011 per cent. This meant that at very low concentrations its precision was superior to that of chemical methods, but at high concentrations inferior, with the two methods having similar precision for concentrations somewhere above 0.01 per cent.

Recently, however, great improvements in precision have been made in the spectrographic method. At the recent fourth summer conference on Applied Spectroscopy held at the Massachusetts Institute of Technology, three groups of papers reported results which showed precision as great as that of chemical wet methods, the average deviation of successive determinations on the same sample being less than 3 per cent. As the spectrographic technic becomes more widely used it seems reasonable to expect a general increase of precision until any quantitative can be carried out as accurately spectrographically as by the accepted chemical wet methods and much more readily.

Twenty Elements Offer Difficulties

The 20 elements commonly considered not susceptible to spectrographic analysis, either qualitative or quantitative, are the permanent gases, the four halogens, sulphur and selenium, polonium, actinium and proto-actinium, thorium and uranium. To these are usually added carbon in quantitative determination, and almost all negative radicals and molecular aggregates, these being usually broken down in the arc or spark to their constituent atoms.

If we examine this list in detail, we soon find why these elements are difficult to handle. Their atoms fall into two categories, those which are unusually difficult to excite to emit light, and whose sensitive lines therefore fall outside of the part of the spectrum usually examined, and those which have so many lines that none are particularly sensitive. That these difficulties can be overcome by new methods which need development is the thesis of the present paper. The preliminary development of these methods which has already been started will be outlined below, after certain general considerations about routine spectroscopic analysis as now practiced have been discussed.

Qualitative Analysis Is Simple

Qualitative analysis with the spectrograph is a simple process. A small sample of the material to be analyzed is placed in an electric arc or spark, its molecules are there automatically dissociated into their constituent atoms, and these are stimulated by the electric current to emit light. This light is sent through a spectrograph which analyzes it into its constituent wave-lengths, recording them as spectrum lines on a photographic plate. Each element emits a known pattern of lines which have been determined by previous workers and are recorded in printed tables, and the lines on the plates can be positively identified with the elements which have emitted them merely by locating their positions on the plate.

This gives a quick and sure method which involves no guess-work, for it is not necessary to know in advance what type of atom is being looked for, so as to try one reaction or another. A single exposure in the spectrograph will suffice for all elements required, so long as they are among the 70 mentioned above.

Quantitative Analysis

Quantitative spectrographic analysis involves only a refinement of the qualitative method, with the additional determination of the amount of light emitted by each type of atom, which can be used as a measure of the number of atoms present. At very low concentrations, the amount of light in any spectrum line is directly proportional to the number of atoms emitting it, which gives a very convenient basis for quantitative work. At higher concentrations, and under different conditions, the number of variables connecting concentration with intensity is so great that only a null method is satisfactory, and the sample must be analyzed by being duplicated as closely as possible with a mixture of known content which emits lines of similar intensity. This is not so difficult as it sounds in cases where concentrations under 1 per cent are involved, for then the various constituents influence each other not at all in most cases, and it is possible to work on a number simultaneously.

The growth of the spectroscopic method of analysis has been to such a large extent empirical that it is not surprising that the literature is filled with artificial distinctions and dogmatic but only partially correct statements which in many cases do not apply. There is fundamentally only one correct method of quantitative analysis by means of the emission spectrum, yet in the literature one reads of Occhialini's method, Ramage's method, and a host of others, which to the uninitiated presents a confusing array of possibilities. The scientists whose names are attached to these various methods have made contributions of greater or less importance to the advancement of the art, but these contributions have all taken the form of short-cuts or modifications in the minor details of technic rather than fundamental changes in procedure.

Stages in the Basic Method

The basic method can be broken up into the following stages:

1. Preparation of the sample for analysis.
2. Excitation of its constituent atoms to emit light of a definite though unknown amount per atom.
3. Analysis of this light into its component lines by means of a spectrograph.
4. Photography of these lines under controlled conditions.
5. Determination of the intensity of the light in each line.

Let us first consider the selection of the spectrograph. I have never known anyone who, when he had purchased an instrument of sufficient size, was disappointed in what a spectrograph would do. Quartz prism instruments are most widely used, since the ultraviolet region is for analytical purposes even more important than the visible region of the spectrum. Quartz instruments are now manufactured in three standard sizes, designated the small, medium, and large respectively. The small size is used mainly for absorption work, which is not yet of importance metallurgically and hence is not discussed in the present paper. While the medium size, which costs less than half what the large size does, can be used quite satisfactorily for many elements such as copper, the alkalies and the alkaline earths, it is less handy for ferrous materials, and the large size is really needed for general work.

A convenient form is the large Littrow type, which has reached a development that leaves little to be desired in a prism instrument. These can be obtained with two sets of optical trains, one quartz and one glass, which are interchangeable at will and which make the instrument usable throughout the visible as well as the ultraviolet spectrum.

While the prism type instrument is used almost exclusively in industrial work at present, there is another possibility that should not be overlooked, which should be of great future importance. This is the diffraction grating, which has the advantage of giving a very simple relation between the position of a line on the plate and the wave-length which serves to identify it. More important still, the same grating can be used in the ultraviolet, the visible, and the infrared regions, so that duplication of optical parts is avoided. Most important of all, the number of gratings available is constantly increasing, and will increase the faster, the greater the demand, while the amount of good crystal quartz available for prism material is decreasing. Even at present, a good grating costs no more than a good prism, and can be made to do more.

Use of the Diffraction Grating

A statement frequently found in the literature, especially that published abroad, is that the diffraction grating cannot be used for spectrographic analysis, since it is fragile, wastes most of the light falling on it, and has ghost lines which mix with the real lines and cause incorrect results. The man who first made that statement really believed it, but it gets more amazing year by year as the number of analyses made with grating instruments increases. As to fragility, most of the first gratings ruled back in the 1880's are still in use, and a number of metallurgical laboratories, including that of the Watertown Arsenal, use grating instruments exclusively. As to wastefulness of light, even the standard type of quartz spectrograph utilizes less than 1/10,000 of the light emitted by the source being studied, and very seldom do the exposures taken with a grating require more than 60 seconds.

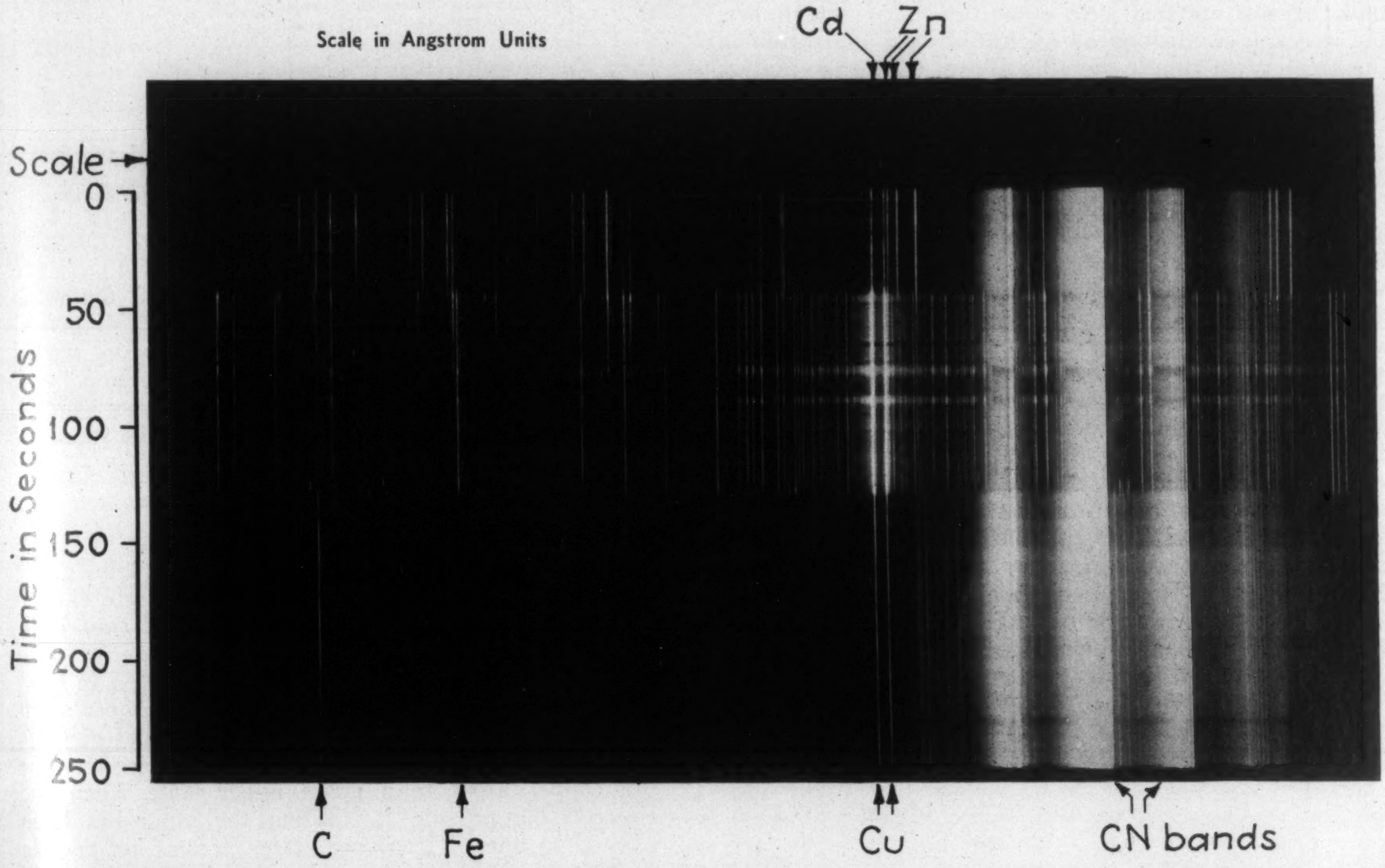
In fact, with ordinary sources and with prism instruments, it is sometimes desirable to artificially lengthen the time of exposure in order to have a more truly representative burning time for the source. Only in extreme cases is the greater brightness of the prism

A Portion of the Spectrum of Iron Taken with the 35 ft. Grating Shown in the Illustration of a Portion of the Track of the 35 ft. Grating System.

over the grating of importance. Some of the new aluminum-coated gratings are surprisingly fast. A large high dispersion grating which I have recently tested throws 60 per cent of its light into one spectrum, and gives good exposures in two seconds.

As to the ghosts or spurious lines—in most modern gratings these have been reduced in intensity to the point where they do not even register photographically except in over-exposures to strong lines. Even if a grating has ghosts of intensity greater than 2 per cent of the main line, which is an unusually high ratio, it can often be used, since the greater dispersion of the grating instrument over the prism instrument gives greater separation of the lines, and they can usually be distinguished from the lines in which one is interested.

Fig. 1.



Why Grating Spectrographs Are Used Less Often

The reason grating spectrographs are used less often than prism spectrographs is very simple—there are comparatively few gratings, and it has not been found possible to turn them out at will like prisms. From 50,000 to 200,000 parallel lines from 1/15,000 to 1/30,000 of an inch apart must be ruled on a mirror, each at an equal distance from its predecessor.

The greatest problem to be solved has been a metallurgical one, to obtain a metal which can be accurately figured and polished, like glass, and at the same time does not wear out the diamond ruling tool too rapidly. Speculum metal has been used largely in the past, but recently great strides have been made by figuring a glass mirror, evaporating a coating of chromium on this, and then on this a coating of aluminum. The ruling is done in the soft aluminum surface, which gradually protects itself with a thin transparent film of oxide, giving a brilliant reflecting surface for all wave-lengths.

As mentioned above the concave diffraction grating can be used in any region of the spectrum. When used with an auxiliary mirror and illuminated with parallel light, it gives stigmatic images like those of a prism spectrograph, and it has the advantage of a practically uniform wave-length scale, rather than one which is crowded at the red end and sparse at the short wave end. Grating spectrographs are now being put out commercially and as the number of gratings available increases so that commercial manufacturers can rely on a source of supply, and the amount of optically useful crystal quartz diminishes, we can expect the grating to increase in use. Most persons who have used both grating and prism instruments prefer the grating for spectrographic analysis.

Source of Light

Let us turn now to consideration of the source of light. This, which is usually an electric arc or spark, but which might take any one of a number of other forms, has two functions. The first is to vaporize the material under investigation, for only then are its constituent atoms or molecules sufficiently separated that each can emit the light characteristic of the element; these atoms must then be bumped into by fast moving electrons, or by other atoms or molecules, or by light emitted by other atoms, so that they will be excited to emit light. Actually all three of these exciting processes are present in the arc and in the spark.

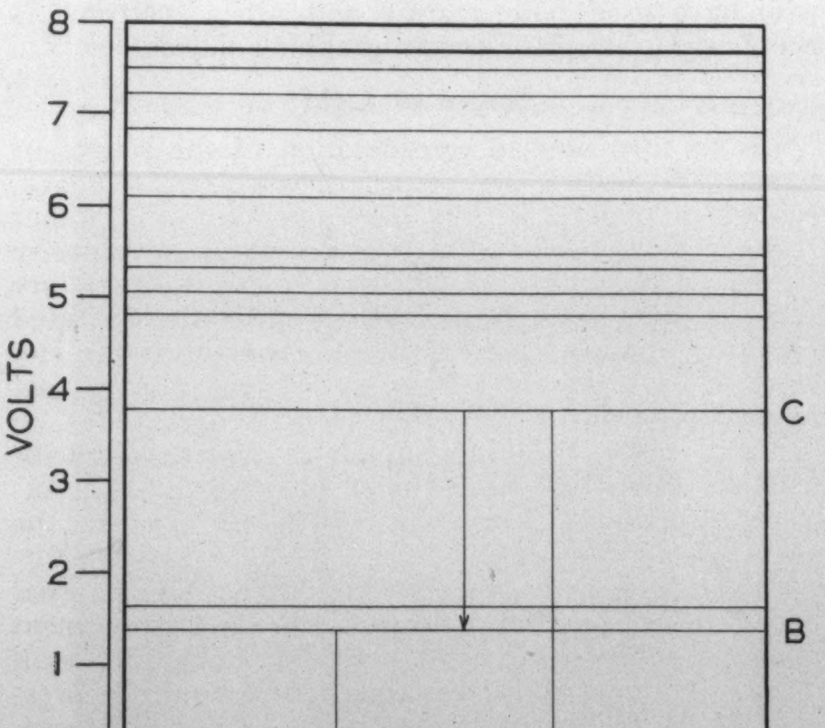
That the mere process of vaporizing the material usually dissociates its molecules into their constituent atoms is a happy circumstance, since molecules emit many more spectrum lines than atoms, and the presence in the source of dozens of molecules with each type emitting its characteristic spectrum would lead to hopeless confusion. The metallic atoms, usually forming the positive radicals, detach themselves readily and are easily excited.

The light source is that phase of quantitative analysis which is now weakest and which would probably show the greatest improvement for a given amount of attention. The basic method requires that the unknown sample be treated exactly like the standard samples with which it is being compared. This means not only that the concentrations of the materials in which one is interested must be similar, but that the matrix must be similar. The matrix is the great bulk of the material the constitution of which sets the average conditions of excitation and ionization in the arc. With simple metallic alloys, where the matrix is simply iron or copper with two or three other constituents, the matrix of the unknown is easy to duplicate. But even then great care must be taken to have unknown and known samples treated identically.

In Fig. 1 is shown the spectrum of 50 milligrams of brass turnings arced in a graphite holder. A very short slit has been used, and the photographic plate has been moved parallel to the lines so that the variation in the rate of burning of the different constituents with time can be observed. At the top of the picture, immediately after the arc was struck, we find lines of zinc, cadmium, lead, and copper predominating. After a few seconds the first three of these becomes burned out, the copper lines become much more intense, and iron lines appear in great profusion. Just before these fade out at the end of 80 seconds more, there is a flash rich in calcium and aluminum lines, and finally we see nothing but the copper lines, now much fainter, a greatly enhanced carbon line (weak before because harder to excite than the metals), and the familiar cyanogen bands formed when carbon is burned in air, now greatly strengthened.

What limits the sensitivity of the spectroscopic method in a given case is not the small amount of light that the atoms available will emit, but how much other light is emitted in the background to drown this light out. After all, we can excite a given atom as many times as we wish if we can hold it in the arc stream long enough but, while we do this, the background intensity is rising. If we had taken a single exposure of the usual type in the case of Fig. 1 we would have such background intensity that the weak Ca and Al lines which flashed only for a brief period would be lost. It is easy to see what errors would result if we compared the intensity of the iron lines, say, in the intermediate state for the unknown sample, with their intensity in the initial state for the standard sample.

Fig. 2.



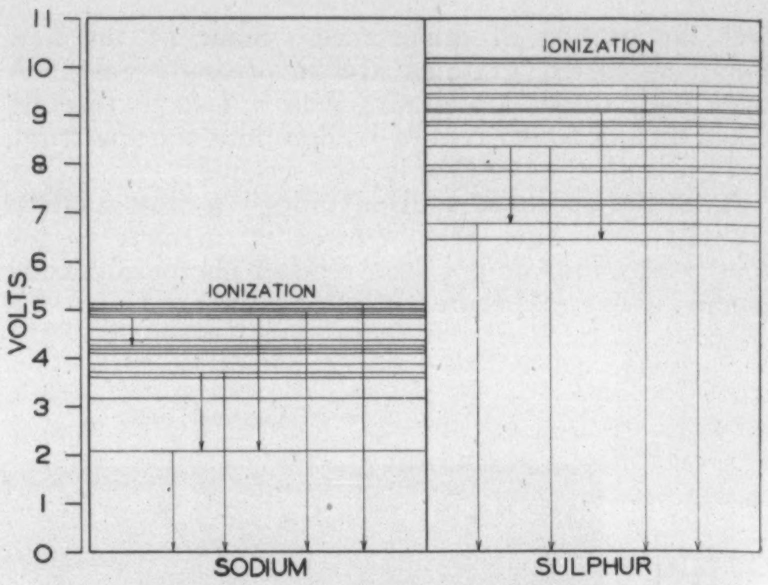


Fig. 3. Comparison of the Diagrams for Sodium and Sulphur.

Exciting an Atom to Emit Light

Let us now consider what must be done to excite an atom so it will emit light. It has been known for some time that atoms possess various discrete energy states or levels, and that an atom cannot emit light unless raised from its lowest or normal state. to some one of its higher states. This is illustrated in Fig. 2, where some of the energy levels of the copper atom are shown plotted out in terms of the number of volts through which an electron must fall in order to raise the copper atom to a given upper state when the electron bumps into it. When the atom has been excited to one of its upper states, it will not remain in that condition for any length of time, but will shortly radiate its surplus energy as light and return to its lowest state. This light will be radiated as a spectrum line whose wave-length will be the shorter, the greater the voltage difference of the two states. Thus to make a copper atom radiate the line corresponding to wave-length 3247 Angstrom units, we must excite it from state A to state B, from which it will then return to state A while emitting the line.

If we excite the copper atom to state C, it may be able to return to state B, and then to state A, emitting two lines; or it may return directly from C to A, emitting one. Since, of the millions of atoms present in any source, some will choose the first option and some the second, whenever we excite the atoms to state C, we can expect lines C-B, C-A, and B-A, to appear.

The importance of this concept is seen at once when we have a mixture of atoms in a vapor, as we always have in a quantitative spectrographic analysis, these atoms having different energy levels. In Fig. 3 we compare the diagrams for sodium and for sulphur. Obviously it is much easier to excite a sodium atom to emit light than to excite a sulphur atom, for its energy levels are all lower.

Importance of Ionization Potentials

Even more important than the height of the energy levels in an atom, which are measured by their so-

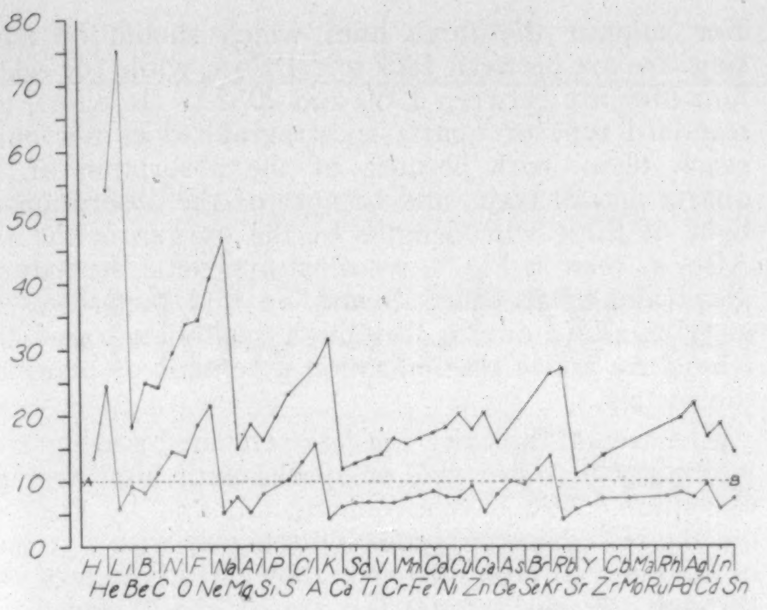
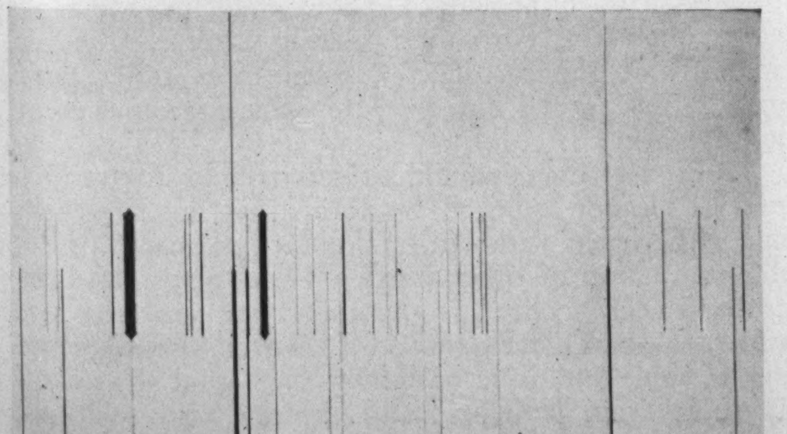


Fig. 4. Ionization Potentials of a Number of the Chemical Elements.

called excitation potentials (voltages required to excite them) are the ionization potentials, which measure the amount of voltage an electron must fall through in order to knock an electron in the atom clear up through the various energy levels and out of the atom entirely, thus ionizing it. In any electrical discharge such as the arc or spark, many of the atoms are ionized, and the ease or difficulty with which this occurs controls the average level of ionization of the discharge. This average ionization level may be likened to temperature; an arc burning in sodium vapor is relatively cool from this standpoint, and if a few sulphur atoms were immersed in it, they would not be excited because, as shown in Fig. 3, the lowest sulphur energy level above its normal state is still higher than the sodium ionization level. If, however, we had an arc burning in sulphur vapor (in a vacuum, of course, or the sulphur would not stay in the atomic form), and then introduced a few sodium atoms, these would be thoroughly excited and the sodium lines would appear strongly. If we added too much sodium, however, (more than something in the neighborhood of 1 per cent) we would "cool off the arc", since the sodium atoms would begin to rob the sulphur atoms of the excitation.

That we can analyze for metallic elements so successfully in mixtures by means of the light their atoms emit is due to the fortunate circumstance that their ionization potentials are nearly all the same, ranging from 5 to 10 volts. The alkali metals have unusually low ionization potentials, so their presence in quantity in a sample tends to depress the excitation of other atoms. All of the permanent gases have high ionization and excitation potentials, running up to 24.5 volts for helium.

A small Section of the Spectrum of Iridium with Iron Comparison Spectrum Photographed with the 35 ft. Grating Shown in the Illustration of a Portion of the Track of the 35 ft. Grating System.



A very simple rule gives the voltage which an electron must have to excite an atom to emit a line of a given wave-length. The voltage required is equal to 12,340 divided by the wave-length of the line in Angstrom units, provided the line in question has as its lower state the lowest energy level in the atom. If it does not, the voltage required will be that required to raise the atom from its lowest state to the upper state of the line in question.

Elements Difficult to Excite in Presence of Others

We are now in a position to see why some elements are difficult to excite in the presence of others. In Fig. 4 are shown the ionization potentials of a number of the chemical elements. The horizontal dotted line A-B marks ten volts. It is apparent that all of the gases, the halogens, and sulphur and selenium lie above this line, while the metals lie below it.

If we remove an electron from an atom by ionizing it, we still have an atom capable of emitting light, but the character of its spectrum changes completely. In fact, it resembles more closely that of the un-ionized atom preceding it in the periodic table than any other.

How sensitive an element is to spectroscopic analysis i.e., how few atoms of that element will emit enough light to be determined spectrographically, depends not only on how readily its spectrum lines can be excited, but on how many spectrum lines it can emit. Thus an element like sodium, or any other alkali, which at most can emit only several hundred lines in its un-ionized state, naturally emits each of these lines more strongly than could a molybdenum atom, which with the same total excitation available must emit several thousand lines. The reason the last four elements of the periodic table are included in our list of elements not measurable spectroscopically is that they can emit hundreds of thousands of lines, and none of these are of outstanding strength, or sensitivity.

The elements in the first column of the periodic table have simple spectra. Those in the next column have slightly more complicated spectra. The further to the right in the periodic table one proceeds, the more complicated in general are the spectra. But we have said that removing an electron from an atom, even temporarily, and exciting the resulting ion will give us a spectrum like that of a preceding column of the table. Several electrons can be removed; thus by taking three electrons from a titanium atom we make it like potassium for a millionth of a second or so, and during that time can make it emit a very simple spectrum. In this way, as experiments by D. P. Merrill and the writer have shown, it is possible to make an element ordinarily insensitive to spectroscopic analysis much more sensitive, merely by using a type of source involving high ionization. High vacuum technique is necessary for this at present, which confines its usefulness to the laboratory, but works methods will undoubtedly be devised for doing the equivalent of this.

Similarly, as can be seen from Fig. 4, using higher stages of ionization tends to equalize the excitation of the different atoms. Thus sodium when ionized emits a very complex spectrum, making it less sensitive, and is harder to excite than ionized magnesium. Using the higher stages of ionization gives us a new degree of freedom to work with, and the absolute sensitivity does not decrease appreciably.

We have seen above that difficulty of excitation (high voltage electrons required) goes with shortness of wave-length of the lines. The gases are difficult to detect spectrographically in the ordinary way not only because they are hard to excite, but also because their principal spectrum lines lie in the region of wave-length shorter than 2000 Angstroms. This region has been studied extensively in scientific laboratories, and there it is usual to find lines of carbon, oxygen, etc., appearing in almost all spectrum photographs, so that they are relatively as sensitive as sodium is in ordinary work. While the vacuum methods needed are not now practical for industrial work, they could be made so if the need arises.

Analyses for Sulphur and Selenium

Sulphur and selenium analyses are very important and are rather difficult to carry out with chemical wet methods. Two years ago Merrill and the writer undertook a series of experiments which showed that sulphur and selenium could both be handled quite well by means of the spectrograph. As soon as we looked into the theoretical reasons which showed why sulphur and selenium show "no raies ultimes or sensitive lines" as given in the tables, it was possible to suggest four different ways of handling these two elements. Three were of the type now practicable only in the research laboratory, but the fourth gives promise of being useful generally.

It is possible, on theoretical grounds, to predict in advance which of the spectrum lines of an element will be most sensitive, and usually also to predict where in the spectrum these lines will be found, if they are not known. A study of the data indicated that sulphur and selenium should both have sensitive lines, but that these all lie at wave-lengths shorter than 2100A, which is the lower limit of most quartz spectrographs. For sulphur the three lines which should be most sensitive are between 1807 and 1826A, while for selenium they are between 1960 and 2062A. In short, the standard type of quartz spectrograph does not quite reach them, both because of the absorption of its quartz optical train, and because of the absorption of light of these wave-lengths by the oxygen in the air. Also, as seen in Fig. 4, we must overcome the natural disadvantage at which S and Se find themselves in metallic alloys due to their high excitation potentials, which are above the ionization potentials of many of the metals.

The second difficulty can be overcome by using arcs with very high current, or sparks with high average excitation. We have overcome the first by flushing out the sealed spectrograph continuously with a stream of commercial tank nitrogen, allowing this to leak out through the slit against the arc or spark placed directly in front of it. If a lithium fluoride prism or a diffraction grating can be used instead of the usual quartz prism, so much the better.

We have successfully analyzed for sulphur down to the lowest concentrations which we could obtain analyzed chemically in nickel, steel, and other materials.

The standard methods of determining the relative concentrations of atoms from the intensities of the lines on the plate are adequate and have been repeatedly discussed in the literature. The rotating sector disk is probably the most convenient method of varying the light intensity by known amounts, with some simple form of microphotometer or its equivalent to measure the line densities.

If investigations of the type outlined above continue to be carried out at the rate at which they are now progressing in various laboratories, we should have available shortly convenient and accurate methods for analyzing spectrographically any chemical substance.

(Concluded from page 289)

metal is fairly resistant to attack by chromic acid. Copper, on the other hand, is readily attacked and requires frequent replacement.

Ventilating Equipment

Ventilation should be provided for cleaner tanks, hot water tanks, cyanide copper plating tanks, and chromium plating tanks. The standard method of ventilating a chromium plating tank is to suck air from the chromium plating tank into a duct through a narrow slot running along both sides and possibly also along both ends of the chromium plating tank. This duct is ordinarily constructed of steel which, however, should be of fairly heavy gage. Ten or twelve gage is commonly employed and it is a question as to whether steel 1/8 in. thick would not be justified on the basis of greater permanence and greater rigidity. Fumes from the chromium plating tank should be conducted first into a separator of the same general construction as employed for dust collection in a buffing or polishing jack system, except that the cone bottom need only have a slope of about 15 deg.

A trapped outlet should be provided at the bottom of the cone, the trap being of sufficient depth to seal the collector against air being carried in under the suction maintained in the system. The outlet of the collector should be connected into the suction of the fan. The advantages of such a collector are that chromic acid fume does not reach the fan. When chromic acid fume does reach the fan, the fan acts as a separator and chromic acid collects in the bottom of the fan, from which it may not readily escape. The collector also has the advantage of preventing the discharge of droplets of chromic acid into the atmosphere, damaging and rendering near-by property unsightly.

Ventilators for the other tanks may be of the same general construction except that it is usually not necessary to move as much air per square foot of surface of the tank, and it is further usually satisfactory to simply provide these ventilators for the side of the tank away from that used by the operators. It is also unnecessary to provide a fume collector for tanks other than the chromium plating tank as the air, steam, and fumes collected from these other tanks may be discharged into the atmosphere without creating damage.

Plain steel ducts should be satisfactory for ventilation of cleaner tanks. The author has not personally had experience with really satisfactory materials for the ventilation of other tanks. Terne plate (lead-tin-coated steel) has been proposed for ventilators for acid and chromium plating tanks. However, the lead coating is thin, and is attacked by the liquid drawn off as fume from both acid and chromic acid solutions. Vulcanized rubber coatings should be permanent for ventilators on acid tanks, and the proposal of vitreous coated steel for chromic acid fume systems sounds interesting.

How and When Does a Fatigue Crack Start?

By PROF. H. F. MOORE

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MECHANICAL FAILURE OF A METAL part of a machine or structure may take place in at least four ways: (1) by elastic buckling, (2) by plastic deformation due to "slip" within crystalline grains of the metal, (3) by slow continuous flow or "creep", and (4) by fracture. In this article only failure by fracture is discussed.

Destructive fracture in a metal part is always progressive. It starts at some spot and spreads. The spread may be very rapid, as in the case of the ordinary tension specimen of brittle material; very slow, as in the case of fracture following long-continued "creep" under a steady load; or intermittently progressive, as in the case of fracture under repeated loading, commonly but rather inappropriately called "fatigue of metals." Under repeated stress, when the crack has spread far enough there follows a sudden fracture through the remaining uncracked metal in the crack-damaged cross-section. The spreading "fatigue" crack originates in a region where plastic "slip" has taken place, but while a fatigue crack starts from a region of slip, slip by no means always causes a fatigue crack.

To explain the present day view of the genesis of fatigue cracks, it is necessary to consider, very sketchily, the atomic and the crystalline structure of metals. So far as is known today the fundamental "building block" for a piece of metal is the space lattice unit cell, a group of atoms arranged in a definite geometrical pattern. For alpha iron and steel the space lattice unit cell consists of nine atoms, one at each corner of a cube and one in the middle (body-centered cubic space lattice). (Each corner atom of a body centered cubic unit cell is shared by seven other unit cells.) For most of the non-ferrous metals the space lattice unit cell consists of 14 atoms, one at each corner of a cube, and one in the center of each face (face-centered cubic space lattice).

Space Lattice Unit Cells, Crystalline Grains and Crystallites

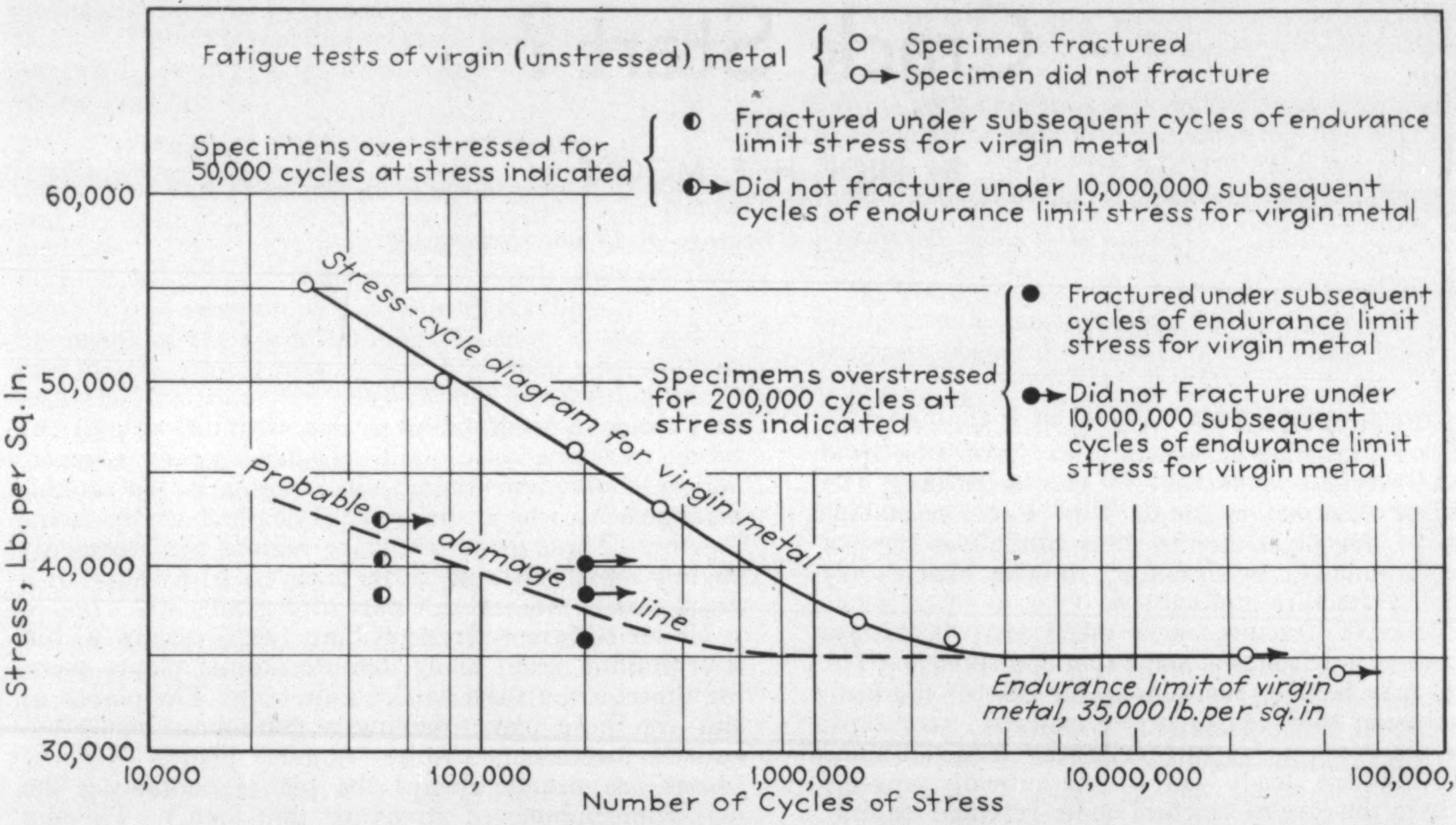
Crystals, or better crystalline grains, of metals are made up of a large number of space lattice unit cells with the cells fitting together and each cell "oriented" in the same direction. A piece of metal is made up of very many such crystalline grains, with differing orientation of space lattice unit cells from grain to grain, and a consequent region of irregularity in atomic arrangement where different crystalline grains come together. These grain boundary regions are frequently slightly more resistant to the progress of a "slip" or a crack than is the interior part of a grain.

Under sufficient stress, gliding (slip) occurs within a crystalline grain along definite atomic planes passing through the space lattice unit cells. The planes of slip are those planes having a maximum separation between adjacent similar atomic planes. (These planes are nearly always the planes containing the maximum number of atoms per unit area.) The slip involves a shifting of the atoms on one side of such an atomic plane with reference to the atoms on the other side. Now the direct effect of this slip is to cause permanent distortion of the metal accompanied by *increased resistance to further slip*. The reason for this increase is not yet entirely clear[1] but it has again and again been demonstrated by experiment. It is probably accompanied by a tendency to slight rotation of space lattice unit cells with the consequent flexure of the original atomic planes, and a tendency to break up crystalline grains into "crystallites" having slightly different orientations from the space lattice units of the unstressed grain. This flexural action would tend to cause severe stresses at the boundaries of incipient crystallites, and, if severe enough, would cause localized fracture of atomic bonds, and consequent very minute cracks. Now a crack always means concentration of stress at its root, and thus, under repeated loading, tends to be self propagating.

Two Opposing Tendencies

We have, then, two opposing tendencies in a metal subjected to repeated stress—a strengthening tendency due to increase in resistance to slip, and a weakening tendency to start spreading cracks. Moreover, slip has a tendency to shift stress from those regions which were originally most stressed to adjacent areas, originally less stressed. Hence repeated stress may proceed for many cycles before sufficient cumulative atomic distortion has occurred to start a spreading crack—or, if the stress be low enough, some atomic distortion may occur but not reach a sufficient magnitude to start a crack at all.

If the foregoing is a fairly accurate picture of the behavior of metal under repeated stress, it is evident that a very slight variation in the crystalline structure of a metal and the existence and location of minute defects may be of prime importance in determining when and where a fatigue crack starts—or whether it starts. (Some investigators hold that there are natural planes of weakness in a crystalline grain of metal, and that "crystallites" form along such planes. Such planes of weakness, if they exist, are many space lattice cells apart. Their existence and the explanation of it are matters of much discussion among metallurgists and atomic physicists.)



We might, indeed, close this article here with the statement that the factors in this problem of a fatigue crack are so complex, and many of them are so unpredictable (e.g. the liability of regions of greatest weakness to coincide with regions of maximum stress) that no precise determination of the time when a fatigue crack will start, or, indeed whether a fatigue crack will ever start, is possible.

Tests for Detecting Fatigue Cracks

Several test methods are, however, available which have been used with some degree of success to detect fatigue cracks in their early stages, or at least before complete fracture has taken place. The most obvious method is that of direct visual examination of the surface of a member subjected to repeated stress—most fatigue cracks start at the surface. One such method, which is non-destructive, consists of covering the surface with oil, which penetrates any cracks, next wiping the oil from the surface, and then coating the surface with whitewash. Then the member is struck sharp blows, and at the same time rotated slowly, forcing retained oil out of cracks and discoloring the whitewash coating.

Another method, a destructive test, uses etching with acid, which widens cracks so that they can be readily seen. A somewhat more delicate method consists in examining the surface with a low-power microscope. This method is not very effective unless the surface is polished. Any crack which can be detected by either of these methods is almost sure to have reached the spreading stage, if it is located in a region of high stress.[2]

If a piece of iron or steel is magnetized, or if a piece of non-ferrous metal has a heavy electric current passed through it, there is a tendency to cause magnetic poles at any crack, and if fine iron dust is sifted over the piece, particles of iron will adhere along the line of the crack. This method has been used by Rawdon in the metallurgical laboratories of the Bureau of Standards, and has been developed commercially by A. V. DeForest under the name of "Magnaflux".[3] The sensitivity of this method is probably somewhat greater than that of the whitewash method.

An indirect method of detecting an early stage of fatigue cracking is the determination of the "probable damage" diagram, which was first carried out by French.[4] The stage of cracking determined by this method is that at which the crack has progressed far enough to lower appreciably the fatigue strength of the virgin (unstressed) metal. The endurance limit (which measures fatigue strength) is first determined by fatigue tests of a number of specimens at various stresses (See illustration). Then a few specimens are subjected to any given number (N) of cycles of stress above the endurance limit of the virgin metal, using a different overstress for each specimen. Next each of these overstressed specimens that remains unbroken is subjected to cycles of stress equal to the endurance limit of the virgin metal. If a specimen breaks, the "probable damage line" at N cycles lies below the stress value to which that specimen was originally subjected—the fatigue crack has progressed far enough to weaken the metal appreciably. If a specimen "runs out" to (say) 10,000,000 cycles without fracture, the "probable damage line" at N cycles lies above the stress value to which the specimen was originally subjected, and no fatigue crack has developed far enough to lower the fatigue strength of the metal appreciably.

By making tests for different numbers of cycles of overstress (N′, N″, etc.) points on the "probable damage line" may be located, and the line drawn as shown in the chart. Any point on this line indicates the number of cycles of stress of a given magnitude and range necessary to weaken appreciably the resistance of the virgin metal to repeated stress. The determination of this stage of development of fatigue crack seems to have possibilities as a practical though approximate indication of the beginning of a fatigue crack. At the present time the technique of the test is somewhat difficult, owing largely to the slight uncertainty in determining the endurance limit of the virgin metal.

X-Ray Diffraction Diagrams

The use of X-ray diffraction diagrams for detecting the start of a fatigue crack is being studied in various laboratories. When X-rays impinge at a small angle against the surface of metal, they are reflected from atoms at the surface and slightly beneath the surface. When the reflected rays are caught on a sensitized plate, a definite pattern is formed, the pattern depending on the type and orientation of the space lattices of the crystalline grains affected.[5] If the specimen used consists of a single crystalline grain the pattern consists of spots; if the specimen is a multi-grained piece of metal (such as an ordinary piece of iron, steel, copper, aluminum, etc.) the pattern of dots frequently outlines rings. As the crystal structure breaks up into crystallites, under the influence of repeated stress, these rings become more nearly continuous. When the fracture stage is reached, some observers have noted a widening of one or more of these rings. (Recent investigations in the X-ray laboratories at the University of Illinois by J. B. Baker and by M. M. Beckwith indicate that in large crystals of lead the image of a crack can be detected in the shape of the diffraction spots.) Further study of this X-ray diffraction method of detecting the beginning, or at least an early stage, of fatigue crack development seems a most promising field of research.[5]

We have, then, a promising hypothesis of the mechanism of the development of a fatigue crack—or for that matter of any fracture in a piece of metal. Starting from the distortion caused by slip within a crystalline grain of metal, continuing with slight fragmentation of crystalline grains and the formation of "crystallites," and entering the stage of disastrous crack formation with a distortion of space lattice cells in the grains and the more marked breaking apart of crystallites, a crack of appreciable size forms and spreads, with stress-concentration at its ever advancing root until the metal is so weakened that sudden fracture of the remaining sound metal occurs.

The precise determination of the beginning of any of these stages seems to be so much a matter of chance occurrence and location of unfavorably oriented crystalline grains and minute defects that it seems a hopeless task. However, there are various methods of detecting a fatigue crack in a fairly early stage. Some of these methods have been tried with a considerable degree of success, but none of them have been developed into a reliable routine test for quality of metal. It is to be hoped that the study of the fatigue crack and its development may prove to be another case in which the complicated research test of today is the parent of the simple and reliable acceptance test of tomorrow.

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[3] H. J. Noble. "Magnaflux Inspection Methods in Airplane Engines," METALS AND ALLOYS, Vol. 7, July 1936, pages 167-170.

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A PAGE OF CHUCKLES

A Little Mirth for Metallurgists

Texas Celebrates!

To the Editor: I enjoyed so much reading several of the "Chuckles" regarding "revolutionary metals and processes", published in METALS AND ALLOYS, that I feel that I should share this one with you. Statements in quotation marks are taken from literature supplied to me from the manufacturer, along with a sample of this "new" material.

"Oman Non-Friction Metals"
(Maybe this should be Oh! Man!?)

> "This metal is a new discovery, the result of chemical research, with characteristics and qualities that are in no other bearing metal on the world market today. Its character and quality is entirely different from all other metals. . . . Few know the difference between an alloy and a solidified emulsion. Oman metal is a solidified emulsion of lead, the heavier metal with a specific gravity of 11.36, held and solidified in perfect distribution in the lighter metal copper, whose specific gravity is 8.95, with any distribution desired, either in a high copper with a low lead percentage, or the reverse, high lead and low copper; the melting point in all instances being the same. . . . A heat of 2000 deg. F. is necessary to destroy the metal . . . attempts by assaying or any other means of a chemical reaction to ascertain as to how the metal is produced would be fruitless for, in the fabrication of the metal, the several other elements used produce a catalystic (?) effect . . . we have not destroyed any of the characteristics as nature established in lead and copper, such as is done in all alloys."
>
> "In all alloys of whatever nature a strong point always stressed is the co-efficient of friction. In Oman metal this point is eliminated . . . a heat of 2000 deg. F. is necessary before the metal will soften."

Then, after a page telling how to eliminate bearing "knocks" by properly fitting Oman metal bearings, is the following:

> "In all forms of alloys at present used, the compression and tensile strengths occupy a very important place due to clearance allowed. In Oman metal we have eliminated any importance whatever being placed on either. . . . An attempt on the part of anyone, after the installation of the bearings to say that they did not give the service for which they were installed would be useless for a perfect installation was first made before government representative before the metal was offered to the public and perfect service was obtained. . . . If the results are not obtained by individual interests as desired we immediately know that the proper installation was not made."

All of our metallurgists who have for years been "destroying the characteristics as nature established in lead and copper, such as is done in all alloys". should now hang their heads in shame. Another thing that intrigues me is the "non-friction" quality—now for old perpetual motion!

Hope you find this of interest. It comes from the Oman Non-Friction Metal Co., 415 Caples Bldg., P.O. Box 694, El Paso, Texas.

PAUL S. LANE
Metallurgist.

Page Buck Rogers

One of our Editorial Advisory Board sends in the following letter received by him:

> Dear ————:
>
> Some days ago I noticed an account of the metal they say holds the universe in place—Andor—it has been called by Amperé. There is another, Diolite, that carries thought vibration.
>
> I have been having a very interesting experiment along these lines. The Diolite and Andor are transparent, not effected by heat or cold. I have collected some in a steel wire and in copper. Also have some lead that has an attraction of some sort—I can not claim the Andor or Diolite in that. But some kind of Radioactivity is in it. Also Zinc has been transmitted to Bismuth. If you would be interested in the lead, I will send you a sample to annalysize. The steel and copper I can't do as they are in an Instrument I am building.
>
> Ledeaux undertook to test a piece of copper that had started 100 per cent copper that was found to be 89.10 per cent copper and the rest precious metals in minute particles but an accident happened and they were not able to finish the test. That was the only piece of copper wire that came out of the making of that type.

A Group of Little Chuckles

Time, Aug. 10, 1936, p. 32, describing miniature models of trees and forests in the Harvard University Museum, says ". . . vines, pine needles and cones were etched out of paper-thin sheets of copper *picked up with a magnet.*"

Barron's, Aug. 3, 1936, page 5: "Republic, which has 83 per cent of its capital in the so-called 'light lines,' viz, sheets, tin plate, *scrap,* wire, etc., made a splendid earnings exhibit." Italics ours.

Aneroid, Sask. (Canadian Press).—Firemen here recovered recently from one of the most "shocking" fires they had experienced. A short circuit started a fire in a store. The firemen put it out, but as the whole building was covered with *galvanized tin,* which proved a good conductor, many received shocks in doing so. Italics are ours.—Courtesy of Prof. Wm. Campbell.